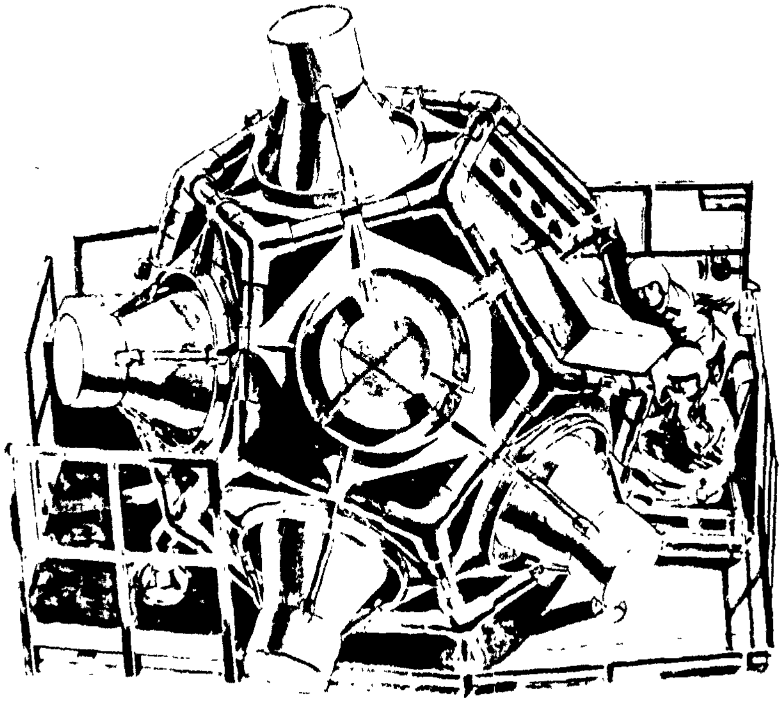
PROCEEDINGS OF THE 1977 IMAGE CONFERENCE.



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Sponsored By

FLYING TRAINING DIVISION
AIR FORCE HUMAN RESOURCES LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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17 18 MAY 1977
UNITED STATES AIR FORCE
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FOREWORD

The 1977 Innovative Modeling and Advanced Generation of Environments (IMAGE) Conference is the first conference specifically concerned with the imagery produced by computer generated visual systems relative to flight simulation. The purpose of the conference is to promote an exchange of information and inspire investigations into areas of needed flying training research. With the increasing number of real-time computer generated visual simulators in the field, it is necessary to expand communications among the user organizations and create a forum to present relevant issues. Pertinent topics include but are not limited to:

1. Efficient and effective modeling techniques.
2. Environmental data base design and structure.
3. Psychological determination of visual cue requirements.
4. Software/hardware developments directly resulting in an expansion of image capability and/or utility.

This conference is inaugurated and sponsored by the Flying Training Division of the Air Force Human Resources Laboratory, the Air Force's prime facility chartered to perform flying training research.

Eric G. Monroe

Eric G. Monroe
Conference Chairman

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Conference Chairman

Eric G. Monroe
Visual Systems Engineer
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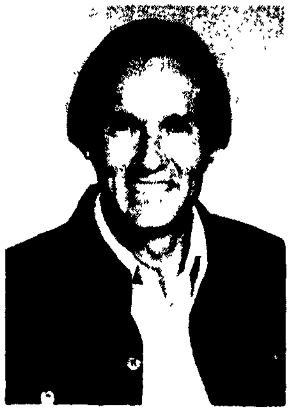

Eric G. Monroe

Eric G. Monroe is the Visual Systems Engineer for the Flying Training Division of the U.S. Air Force Human Resources Laboratory (AFHRL). In this capacity, he has prime responsibility for coordinating the activities of the visual system software personnel for the world's most advanced flying training research device, the Advanced Simulator for Pilot Training (ASPT).

Mr. Monroe was the Project Engineer for the ASPT Phase of the USAF Aeronautical Systems Division's (ASD) Project 2235, "Air-to-Ground Visual Evaluation," with responsibility for the project's supervision and management, in addition to his own technical contributions. Currently, he is also serving as the Project Engineer for the "Area-of-Interest Evaluation" being conducted in conjunction with the ASD Simulator Systems Program Office and the Aeromedical Research Laboratory at Wright-Patterson Air Force Base.

Mr. Monroe has a private pilot's license. He is a member of Phi Beta Kappa and holds the B.A., M.A., and M.S. degrees in mathematics from Washington and Jefferson College, Duquesne University, and Stetson University, respectively. Upon leaving Duquesne University, where he taught for two years, he served in the U.S. Army Chemical Corp with a ROTC commission. Assigned to the Chemical-Biological-Radiological Agency of the U.S. Army Combat Developments Command, he was the Project Officer for a computer-simulated weapons effects study.

Prior to joining the Flying Training Division of AFHRL, Mr. Monroe was a systems Engineer for the Space Division of the General Electric Company in Daytona Beach, Florida. At General Electric, he was responsible for the design and development of the largest computer-generated image environmental data base undertaken until then, and provided data base analyses for a National Aeronautical and Space Administration (NASA) contract.

At the Human Resources Laboratory, Mr. Monroe has been the Project Engineer for numerous studies, written several articles and technical reports on computer-generated imagery, and, in July 1976, proceeded to inaugurate his conception of the IMAGE Conference.

INTRODUCTION TO THE 1977 IMAGE CONFERENCE

ERIC G. MONROE
Flying Training Division
Air Force Human Resources Laboratory
Photograph and Biographical Sketch-See Page 1

The predominant sense a pilot utilizes in flying is that of vision. This conference is in general concerned with visual flight simulation, and in particular with the visual imagery generated by computers.

In February 1975, the Department of Defense published their Report on Flight Simulation which stated the following concerning needed research and development: "Visual simulation and display techniques are the most limiting factors to the capability of current synthetic training devices. While certain advances have made possible the development of limited experimental wide-angle visual systems, additional advanced development is needed to further their ability to satisfy the high resolution, wide-angle, and multi-target requirements of the military mission. Technology has been demonstrated that is capable of adequately creating and displaying the scene required for the straight-in approach for day and night field and carrier landing and take-off. These and other visual simulation capabilities, similar to those used in commercial aviation, have been well demonstrated and have been incorporated in some of the devices now being procured. However, additional research and development is needed in visual simulation to develop wide field of view devices which integrate with sufficient resolution, needed complex target imagery. This capability, if it can be satisfactorily developed, would go far toward realistic simulation of the full range of military missions. The military training tasks that would benefit from such a capability include:

1. Air combat and air-to-air gunnery.

2. Formation flying.

3. In flight refueling.

4. Air-to-ground weapons delivery.

5. Vertical take-off and landing.

Major research and development programs are in process to evaluate experimental wide field of view visual systems and their role in the transfer of learning. Other test and evaluation programs will provide data for defining air-to-air training requirements and techniques, as well as improved air combat

tactics. Additional effort is needed to improve simulation of acceleration and motion, computational technology for sensor and visual displays, the quality of data on aerodynamic flight characteristics, and quantitative and objective measures of pilot proficiency."

This report was published the same month the Advanced Simulator for Pilot Training (ASPT) became operational. Much has transpired in the past two and one-half years along the recommended lines of research. Recent evaluations, such as Air Force Project 2235: Air-to-Ground Visual Evaluation, have established that computer generated imagery provides extremely effective and flexible training capabilities unique in visual simulation. The capability to rehearse scenarios involving numerous other aircraft, both friendly and hostile, surface-to-air missiles, ground fire, flak, and moving ground targets in actual theatres of operation titillates the imagination of the most voracious fighter pilot. Yet these things are possible, and are within the current state of the art. It is up to us to exploit today's imagery through creative and innovative usage.

The need to establish a focal point to serve as a forum for expounding advances made in the improvement of the quality and utility of the image content for computer generated visual systems has been apparent to me for the past few years. With the increasing number of real-time computer generated visual simulators in the field a means of initiating and maintaining communications among the user organizations is needed to promote an exchange of information concerning new developments, techniques, and problem solutions. My views along this line were reinforced through communication with numerous governmental and industrial organizations throughout the country. With this in mind, I proceeded to derive an appropriate acronym and formally initiate the organization of the IMAGE Conference in July 1976. Hopefully, this gathering will perform a catalytic function in evoking a synergistic effort to solve the current problems associated with computer-generated visual flight simulation. For this to occur, we must of necessity know what one another is and has been doing. I would like to take this opportunity to briefly outline the imagery that has been developed for and utilized by the Advanced Simulator for Pilot Training, since it became operational in February of 1975.

The ASPT System consists of two T-37B simulator cockpits separately mounted on six-degree-of-freedom-motion platforms. Each cockpit is surrounded by seven 36-inch monochrome cathode ray tubes (CRT's) viewed through in-line optics, which collimate the light rays to display a virtual image. The pentagonal shaped optical windows are mosaiced to fill seven faces of a regular dodecahedron to give a wraparound field of view of approximately 300 degrees horizontal by 150 degrees vertical. The display imagery is computer generated with a 2560 edge limitation.

The initial environment for the system reflected its original use for research in undergraduate pilot training. It consists of the Williams AFB complex centered on an area 140 by 160 nautical miles, containing such cultural and

topographical features as cities, towns, airfields, roads, railroads, rivers, mountains, etc. An 1800 edge model of a T-37 aircraft was provided for flying formation, and six additional airfields were added to permit cross-country flights.

With the advent of the requirement of visual simulation for the A-10, F-15, and F-16 aircraft, considerable Air Force attention was focused on the capability of current technology to simulate air-to-surface mission scenarios. The Flying Training Division participated in the Air Force "Air-to-Ground Visual Evaluation" (Aeronautical Systems Division Simulator Systems Program Office, ASD/SIMSPO, Project 2235) by modifying the ASPT system to simulate air-to-surface weapons delivery. Provision was made for visual simulation of ordnance ground impact, surface-to-air missile, moving ground target, anti-aircraft artillery, flak, and FAC (forward air controller) smoking of a target in appropriate tactical environments.

As a follow on to this evaluation, a head slaved area-of-interest (AOI) capability has been devised, providing scene detail only in that portion of the entire display to which the pilot is directing his attention. This technique permits the environmental edge density to be increased, since the system edge capabity can now be concentrated within a smaller field-of-view (FOV).

Recently, a study was performed to determine the transition of training to the actual day landing task from performing simulated landing in a night only Computer Image Generation (CIG) system. The data base generated for this study simulates current night only CIG systems containing both point lights and surfaces.

The lack of adequate visual flare and touchdown cues has been a long-standing criticism of flight simulators. A current study addressed this problem by employing six runways differing in the runway surface textural cues to assess their influence on pilot performance.

A special environment was recently generated to investigate two different possible display formats impacting a major ongoing acquisition involving the Army Research Institute and PM TRADE. This data base was designed to demand specific aircraft maneuvers in response to a predetermined ground track.

Currently, we are generating a model of the Davis-Monthan AFB locality and Gila Bend Gunnery Range for the dual purpose of conducting training research and providing the Tactical Air Command (TAC) with interim transition training for future A-10 pilots.

In the near future, we anticipate conducting an aerial refueling evaluation which will require the generation of a number in KC-235 tankers of varying levels of image detail.

As you can see from the agenda, some of the projects I have briefly mentioned will be addressed in further detail later in the conference.

Although much attention has been given to increasing the image processing and display capacity in the past, and rightly so, a disproportionate amount of concern has been applied to increasing the capability of utilizing the technology created. The present manual process of generating environments with relatively limited computer assistance is archaic and deprives facilities employing CIG systems of one of its major attributes, i.e., the ability to generate a library of data bases in a timely manner. Interactive graphic devices should be incorporated which permit real-time interaction between the "modeler" and the computer in building, modifying, and amending the data bases. Data base development is also restsricted, in that most systems can be used for either research and training or data base development, but not both concurrently. Furthermore, non-standardization of data bases precludes the utilization of environments generated at one facility from being directly applied at another. Research and development facilitiesneed the means to rapidly quantify visual scene parameters (the number of edges, objects, models, etc.) on a frame-to-frame basis and the ability to determine the percentage of the system processing capacity being utilized. Software packages should be implemented which would analyze the environmental parametric densities, isolate regions of potential system overload, and recommend alternate solutions. In addition, it is necessary to be able to demonstrate visual environments of varying levels of edge densities, in order to assess the capacity required for future simulator buys. The aforementioned are not technological limitations, but rather the result of the priority given at the time of system design and development.

The behavioral aspect of image requirements is an area much in need of research. For a given task, what visual cues are required for adequate pilot performance? How much scene realism is required? Does color (as opposed to monochrome displays) significantly increase pilot behavioral response? The list goes on and on.

I know that some of us here today are already pursuing these endeavors, and I hope that they will get the necessary priority to assure their accomplishment. With the rapid increase in the processing capabilities, let us not neglect the means of effectively utilizing to the maximum extent possible the imagery we create.

We of the Flying Training Division are extremely pleased with the interest you have shown in this Conference. The list of distinguished representatives of government, industry, and academia in attendance is most gratifying. Over the next two days, twenty papers will be presented, covering various and sundry topics of visual simulation. I would like to take this opportunity to express my appreciation for the time and effort these authors have put forth. Their papers should prove both stimulating and informative. May your experiences at this Conference be most rewarding and enjoyable.

KEYNOTE ADDRESS

Senator Barry M. Goldwater

Barry M. Goldwater was born in Phoenix, Arizona Territory, on January 1, 1909. He was educated in the public schools of Phoenix and Stauton Military Academy in Virginia. He attended the University of Arizona for one year but left school on the death of his father.

Senator Goldwater is a World War II veteran who flew with ATC to India and China. A retired Major General in the U.S. Air Force Reserve, he has logged over 12,000 hours of flying time in 159 types of jet and conventional aircraft.

He began his political career in 1949 when he was elected to the City Council of Phoenix on the reform ticket. In 1952 he was elected to his first term in the U.S. Senate defeating the then Democrat majority leader of the Senate. He was reelected in 1958 and resigned his Senate seat in 1964 to become the Republican Presidential Nominee. He was again elected to the U.S. Senate in 1968 and was assigned to the Senate Armed Services Committee and the Senate Aeronautical and Space Sciences Committee. In 1974, Senator Goldwater was reelected to a fourth term and has been additionally put on the newly formed Select Committee on Intelligence Operations.

Senator Goldwater is the author of numerous books including: The Conscience of a Conservative, Why Not Victory?, Where I Stand, The Face of Arizona, People and Places, Down the Green and Colorado Rivers, and The Conscience of a Majority, Delightful Journey, Arizona Portraits, and Speeches of Henry Fountain Ashurst.

In 1934 Mr. Goldwater married Margaret Johnson of Muncie, Indiana. They have four children, Joanne, Margaret, Barry, Jr., Michael and ten grandchildren.

Senator Goldwater is a member of the Episcopal Church, Masons, Elks, VFW, American Legion, Sigma Chi, and board of directors of the Air Force Historical Foundation. He is the owner and operator of amateur radio station K7UGA-K3UIG-AFA which is now a part of the Military Affiliate Radio System. He is also President of the Arizona Historical Foundation.

KEYNOTE ADDRESS

Senator Barry Goldwater

Colonel Boren, Mr. Monroe, and distinguished conferees, I thank you for asking me to be your keynote speaker at this important Conference. I wlways enjoy coming back to Williams Air Force Base, where, as I am sure most of you know, I have spent a lot of time over the years.

Since your Conference is on simulation I start with the premise that there are some things that cannot be simulated nor should they be.

As long as I am here at Willy, I cannot pass up the opportunity to reminisce for a moment or two. I guess most of you oldtimers remember when Ed Link developed his first trainer in about 1929 and all of the thousands of Links that were used in World War II. I remember the first time I flew a Link, which was in about 1940 and I later met Ed Link sometime during World War II. At about that time I was serving in the old Ferry Command as an Operations Officer of a swuadron. We had Link trainers and like typical military, we were required to fly them a certain number of hours each month. Well, I never could get the other pilots to do their share because they did not like to fly the "Blue Box," so I got a lot of extra Link time. In fact, I really became proficient.

Of course, there was no similarity between that trainer and any aircraft I was flying, and it really did not "fly" like an airplane. But in retrospect, it was a wonderful device and a superb trainer for learning instrument procedures. I am also convinced there was good transfer of learning, to use a term popular here at HRL.

Also, on the plus side was the fact that the Link trainer instructors did not rap your kees with the stick like your instructor pilot did when you made a mistake. That rapping technique certainly did get the students' attention, but if it was used today, I suspect the instructor would probably be cited for some violation of the students' Consititutional rights.

We have come a long way since the learly days of Ed Link and the "Blue Box". I am not sure whether we have come as far with this simulator technology as we have with our aircraft technology but if we have not, we are rapidly catching up. By that I mean the flight simulator can now do just about everything the aircraft can do, almost to the point that the pilot, once he really puts himself into the training mission, treats and thinks of the flight simulator as the real thing. In fact, in his mind, it <u>is</u> the real thing and he is really flying and he encounters all of the sensations and apprehensions associated with flying.

It is this realism where such significant pro-ress has been made over the past few years. Specifically, the development of high fidelity control response and very realistic motion systems put the "feel" into the simulator and got the pilots saying the simulator flew like the real thing - as long as you were IFR. The visual problem has been tougher.

More recently have come the dramatic improvements in visual systems which have given us the ability to have for the first time a full mission simulator. It looks like the potential multiplier in the visual category will be the computer generated image technique which can reproduce many scnees not possible or practical with the model board. The flexibility of this system is probably its greatest attraction because the military pilot and his aircraft represent a multimission capability and, therefore, have a multimission training requirement.

As an aside at this point, I hope one of the goals of this Conference can be to standardize on the term for visual images that are generated by computer. The most common terms are Computer Generated Image (CGI) and Computer Image Generation (CIG). I have no preference, but I do hope you can resolve to all use the same term.

The idea of having one visual system that can reproduce all scenes such as take-off, air refueling, formation air to air combat, air to ground attack along with enemy defenses, and landing represents the ultimate in a system. It is the perfection of this technique that remains to be accomplished because I know we are all aware of the many other applications of such a system. These could include stored programs of worldwide tactical target areas, air to air combat situations taken from the data obtained from our ACEVAL operation at Nellis Air Force Base, and a complete brigade or possibly division ground operation with attack and scout helicopters working against enemy targets. Potentially, the capability is there, but still a lot of refinement and study is needed.

Before we go charging after complete and total real world visual duplication, we need to ask some serious questions. First, how close to the real world must these artificial scenes be in order to achieve the required training benefit? Second, how much are we willing to pay for that capability? Third, will we really know when we have the answers to the first two questions?

At the moment I do not feel confident we have the answers to the first two questions, nor are we especially pursuing their answers. My observation is that we are currently proceeding with the general attitude of, "lets make all of these systems as close to what the real aircraft feels like and what the real world looks like, and if it later turns out that that was really not required, it is better to have erred on the plus side."

I think a review of the magnitude of the flight simulator program over the past few years will support my concern.

To do this, let me now discuss Congress and flight simulators over the past few years because it bears on these points.

We all know that flight simulators have become hot items in a very short time. Not only have they become the "in thing" and very good, they have also become very expensive. For example, one B-52G/H simulator, our most expensive system, is estimated to cost $25 million.

Over the past three years the Senate Armed Services Committee has taken the lead in the Congressional approval of over $786 million for flight simulators and associated equipment. Next year the anticipated FY 1979 request is expected to be about $350 million. Over one billion invested over a four year period!

Some of the statistics associated with these devices are impressive. By October of this year the simulator devices on hand will enable a flying hour reduction of approximately 675,000 hours. This will be a saving of about 565 million gallons of jet fuel and avgas and about $625 million in cost avoidance, although that does not represent a net savings as it has not been adjusted for the cost of operating the training devices. On the average, we will amortize our investment in these devices in about 5 1/2 years. I also point out we are not yet realizing the full benefits of most of the devices the Congress has funded over the past three years.

What those figures also do not convey is the qualitative improvement that our aircrews gain through the use of these new high technology devices. It is this qualitative improvement we must not lose sight of and we must make sure that these devices always remain the means and not the end. This could happen and we must continually emphasize that these devices are not substitutes for aircraft, but that they merely complement and improve the quality of aircrew training and readiness.

To some in the decision chain, simulation and substitution are synonymous terms. We need to correct that misconception wherever it is encountered.

I think that message is now getting through, although a few years back I was more concerned. At about that time the Office of Management and Budget established as a goal for the Department of Defense, a 25 percent reduction in flying time by the early 1980's through the increased use of flight simulators.

Now whoever thought that up, I suspect, was not concerned about getting a qualitative improvement in our aircrew force. To the contrary, the goal was to save fuel, and to do that, flight simulator hours would be substituted for aircraft hours. Apparently, on paper at least, 25 percent looked like a good goal. As far as I have been able to determine, it was an arbitrary, bureaucratic figure and certainly not based on any data provided by the Services.

In May 1976, just a year ago, I conducted the only hearing ever held by the Congress on flight simulators, and I explored this 25 percent figure in depth. It turned out that no one in DOD knew the originator of the idea, and the more we pressed the matter, the more it became apparent that OMB was retreating from this arbitrary position.

The danger, of course, is the way the idea was originated in that it was totally unrelated to the requirement for qualitative improvement and combat readiness.

During the hearing I cautioned that we should not get carried away with the use of flight simulators as a substitute for flying. It would be possible, I suggested, to do 100 percent of one's training in flight simulators and only fly when there was an emergency or war. However, that is not practical because the entire support base exists only to insure that the aircrews have an effective weapon system to fly. This base must be exercised on a routine and regular basis.

For example, think of all the specialists in the Services that can only maintain proficiency in their specialty when their aircrews and aircraft fly.

Think, also, of all the logistic and maintenance systems that must be exercised on a routine and regular basis if they are to have any hope of meeting surge demands during emergency or combat operations.

It is stating the obvious to say that flight simulators cannot shoot down airplanes, drop bombs, kill tanks, provide close air support or kill enemy ships, but is makes the point that flight simulators must not be thought of as substitutes for airplanes, especially combat airplanes.

It would be a mistake to think that achieving a 25 percent reduction in flying time through the use of flight simulators meant there could be a 25 percent reduction in aircraft. Yet, some of the system analysts I am occasionally critical of may come to that same conclusion. Again, I stress that such a conclusion would be a mistake.

For example, referring back to the estimated avoidance of 676,000 flying hours projected as an estimate for FY 1978, that is 14 percent of the total flying hours that would have been required if simulators were not available. By 1981 the percentage is expected to increase to 17 percent.

However, these figures without some further explanation can be misleading. Not all aircraft systems are supported by modern, sophisticated flight training devices. For example, the inventory of some aircraft systems is too small or widely dispersed to support feasible utilization of expensive flight training equipment. When the flying hours for all aircraft systems in the active force are included, the estimated flying hour avoidance for FY 1978 becomes 11 percent, and the FY 1981 estimate becomes about 14 percent.

So, I thik we are proceeding in a prudent way, and the reduction figures we are headed toward are reasonable. However, we do have to remember that the energy policy the Congress is not backing may force us to substitute more simulator hours for flight hours than we would like. At the moment I do not think anyone has a good handle on this.

Now you gentlemen are experts in this business and probably could make the best judgement on what can be substituted with flight simulators in flying training and what cannot. The

expertise of the Air Force Human Resources Lab has pioneered many of the innovative ideas that are operational on flight simulators today.

Certainly, the Advanced Simulator for Pilot Training is a pioneer and ASPT is known throughout the simulator community. I have flown the ASPT, and the substantial and verifiable data gathered on how the human senses relate to simulation and how transfer of learning takes place, is, to me, the correct way to approach the question of, "How much flight simulator time is enough?"

Now this brings me back to my other point about visual systems. We need to continually ask ourselves, to use your vernacular, "How much visual is enough?" Further, "Are images that are indistinguishable from the real world really required?"

Your studies here at HRL have made a major contribution to this field of knowledge. However, I understand your study results are not always the most popular with the operators who possibly have only a gut feeling that flight simulators must reproduce real world conditions to the nth degree possible - otherwide they are not effective.

Here then is the challenge that faces you gentlemen.

Do not goldplate this goose or otherwise it will never get off the ground. Remember that tough budget times are ahead. Make sure you can fully justify the visual systems you propose because in the future, Congress will be examining this justification more closely than ever. Build what is required into these systems, but nothing more and make sure your research is complete before you come to the Congress.

I compliment you on the significant and impressive contributions you have made to this important field.

Have a good Conference.

SESSION I

Chairman

Colonel John V. Kleperis, USAF
Deputy Director, Simulator Systems Program Office
Aeronautical Systems Division

Colonel John V. Kleperis

Col Kleperis was born in Latvia. In 1950 he entered the United States and established his residence in Connecticut. He was commissioned through the Reserve Officer Training Corps in 1957 following his graduation from the University of Connecticut where he earned a Bachelor's Degree in Mathematics. Following pilot training, Col Kleperis was an instructor pilot with the 3576th Flying Training Squadron and flew the T-33. He then attended the Air Force Institute of Technology and received a Master's Degree in Materials Engineering in 1964.

From 1964 to 1965, Col Kleperis was assigned to the Air Force Materials Laboratory as the materials engineer for the C-141. He was assigned to Southeast Asia in 1965 as a Forward Air Controller flying the O-1. After a year at Binh Thy AB, Vietnam, and over 200 combat missions, Col. Kleperis was reassigned to Wright-Patterson AFB--first as a T-29 mission pilot with the 2750th ABW and then as Manager of Collocated Engineering and later as Assistant for Systems Support in the Air Force Materials Laboratory.

In 1971, Col Kleperis returned to Southeast Asia as Chief of the AFSC Liaison Office at HQ 7th AF, Tan Son Nhut AB, Vietnam. Upon his return to the United States in 1972, he was made Program Manager of the PAVE SPIKE laser target designator program at Aeronautical Systems Division, Wright-Patterson AFB.

Col Kleperis next served as Director of Systems Management, Program Management Assistance Group (PMAG), HQ AFSC, from January 1976 to January 1977, when he was assigned as Deputy Director, Simulator System Program Office at Wright-Patterson AFB.

Col Kleperis is married to the former Margaret Dean of Old Lyme, Connecticut. They have two children and reside in Dayton, Ohio.

A VISUALLY-COUPLED AIRBORNE SYSTEMS SIMULATOR (VCASS)-
AN APPROACH TO VISUAL SIMULATION

Dean F. Kocian
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The author received his M.S. in Electrical Engineering from the Ohio State University in 1975 and his B.S. in Engineering from the United States Air Force Academy in 1968. He is currently working as project engineer on the Visually-Coupled Airborne Systems Simulator program for the 6570 Aerospace Medical Research Laboratory. He has been working in the area of visually-coupled systems since 1969. He was the project engineer for development programs on both helmet-mounted sights and displays (HMS/D)including a revolutionary parabolic visor display that used the helmet visor as the last imaging surface for presenting high resolution video imagery to the eye. He has also participated in all the important early flight testing of the HMS/D.

A VISUALLY-COUPLED AIRBORNE SYSTEMS SIMULATOR (VCASS) - AN APPROACH TO VISUAL SIMULATION

DEAN F. KOCIAN
6570 Aerospace Medical Research Laboratory

In recent years Air Force operational units have experienced a continuing trend downward in the number of flight hours in aircraft that can be provided to each individual pilot for training and maintaining proficiency. This comes at a time when aircraft systems are becoming ever more complex and sophisticated requiring comparatively more hours for training to maintain the same relative flying proficiency. With increasing costs for fuel and aircraft and the failure of DoD funding to keep pace with these costs, the trend is almost sure to continue. In adjusting to the realities of keeping overall experience at a satisfactory level and reducing costs, procurement of aircraft simulators has become a necessity.

The rapid proliferation of simulators with no standard technical criteria as a guide has resulted in the evolution of several different design approaches. Most existing visual scene simulators utilize electro-optical devices which project video imagery (generated from a sensor scan of a terrain board or a computer generated imagery capability) onto a hemispherical dome or set of large adjacent CRT displays arranged in optical mosaics with the weapon, vehicle, and threat dynamics being provided by additional computer capabilities.

These large fixed-base simulators suffer from the following drawbacks. The majority of the visual projection techniques used in these simulators do not incorporate infinity optics which provide collimated visual scenes to the operator. Those which do are large and expensive and incorporate large CRT displays. The luminance levels and resolution of these displays are usually low and do not represent true ambient conditions in the real environment. Additionally, hemispherical infinity optics are difficult to implement and this technique requires excessive computer capacity to generate imagery due to the need for refreshing an entire hemisphere instantaneously, regardless of where the crew member is looking. In this regard, existing computer capability is not used effectively to match the channel capacity of the human visual system. There are also generally no stereoscopic depth cues provided for outside-of-cockpit scenes. Another important drawback to these simulators is that the visual simulation is not transferrable to the actual flight environment, i.e., the ground-based system cannot be transferred to an actual aircraft to determine simulation validity. Finally, most existing techniques are very expensive and do not allow the flexibility

of incorporating other display design factors such as different head-up display image formats, fields-of-view (FOV), representative cockpit visibilities, and optional control and display interfaces.

A quite different approach to solving the visual presentation problems of aircraft simulators is to employ the use of visually coupled systems (VCS). For many years it has been the mission of the Aerospace Medical Research Laboratory to optimize the visual interface of crew members to advanced weapon systems. This mission has been primarily pursued in two areas: (1) the establishment of control/display engineering criteria; and (2) the prototyping of advanced concepts for control and display interface. An important part of fulfilling this mission has been the development of VCS components which includes head position sensing systems or helmet mounted sights (HMS), eye position sensing systems (EPS) and helmet mounted displays (HMD).

In the process of accomplishing this work, it has been ascertained that many of the current Air Force air-to-air and air-to-ground weapon systems problems can be related to deficiencies in the configurations of control and display components which interface the crew member to aircraft fire control, navigation, flight control and weapon delivery subsystems. These interfaces tend to either overly task load the crew member or prevent optimum utilization of innate visual, perceptual and motor capabilities. These limitations are especially apparent in fire control and weapon delivery applications where visual target acquisition and weapon aiming are required along with primary piloting tasks. Under high threat conditions, the flight profiles necessary for survivability, as well as mission success, dictate that all essential tasks be performed effectively, accurately and most important expediently. With the recent advent of advanced digital avionics systems, the control and display design issue is further complicated. The proliferation of dedicated control and display subsystems in current aircraft cockpits has necessitated the development of multi-mode displays and control input devices. In addition, more exotic virtual image display devices (head-up display/helmet-mounted display) and unique control devices such as the multifunction keyboard, helmet-mounted sight and fly-by-wire subsystems have appeared. In this regard, the design options open to the avionics as well as control and display designer are great, thereby generating a real need for human engineering design criteria to elucidate the image quality characteristics, information formatting and interface dynamics which optimize the operator interface with these advanced systems.

The process of establishing practical design criteria with the number of options that are available is a laborious and time consuming task, especially if validation in flight environments becomes necessary. Typically, flight testing is very expensive and does not allow flexibility as well as consistent replication of experimental conditions.

Due to these factors, high fidelity ground-based simulation is the only realistic alternative. However, it now becomes necessary to develop simulation methodology, techniques and apparatus which are subject to flight test validation. It is felt that the unique capabilities of a visually-coupled system (VCS - combination of a helmet-mounted sight and helmet-mounted display) can meet the simulation requirements stated above as well as improve upon existing ground based simulation techniques described earlier. It is out of this thinking that the VCASS concept evolved.

A more detailed analysis of the problem has produced a set of characteristics which a more ideal aircraft simulator might possess. Of primary importance is that it should be a flexible visual scene simulation providing synthesized out-of-the-cockpit visual scenes and targets, a representative vehicle whose type can be altered, threat and weapon dynamics, flexibility of control and display configurations, and inputs from sensor or real world imagery. It should be portable if possible and provide alternatives for crew station display options including number and configuration. This simulator should also be useable in both simulated air-to-ground weapon delivery and air-to-air engagement scenarios. Finally, it should be possible to use the same system in ground fixed base and motion base simulators as well as in aircraft.

As an approach to meeting these requirements the VCASS concept and program was initiated. Its objective is to develop and demonstrate a self-contained airborne and ground-based man-in-the-loop visual simulator for the engineering of advanced weapon systems. The approach that will be followed to obtain this objective will be to integrate VCS hardware with state-of-the-art computer image generators to provide a synthesized hemispherical visual space that will display target and environmental images. Included in this approach is the use of real and/or simulated plant dynamics.

The key components of VCASS will be VCS hardware which includes the HMS and HMD. These components are used to "visually-couple" the operator to the other system components he is using. AMRL has pioneered efforts in the research, development and testing of these hardware techniques.

Specifically, the concept of the VCASS is to utilize the HMS as a means of selecting information within a synthesized visual space and to use the helmet display as the visual input device for presenting that information to the operator as a collimated virtual image. This allows head-up display type symbology and/or imagery to be generated to represent a full hemisphere, out-of-the-cockpit view, a portion of which the operator perceives on the helmet display. The scale or size of this

instantaneous portion of the total field is a function of the field-of-view of the HMD. The orientation of the instantaneous field-of-view is determined and selected in accordance with head orientation as measured by the HMS. In other words, if the field-of-view of the HMD is 30 degrees the observer sees a 30 degree instantaneous view of a hemispherical digital symbol set. This instantaneous view moves in a one-to-one correspondence with head movement. In essence, the total hemispherical scene is available to the operator a field-of-view at a time.

A system diagram and pictoral of the functional elements required to accomplish the VCASS are depicted in Figure 1. The operator utilizes conventional control devices (control stick, throttle, rudder pedals, etc.) to input a digital computer which provides the manipulation of the vehicle, weapon and threat states as a function of preprogrammed dynamic characteristics. This information is then used to manipulate synthesized symbology and imagery in terms of orientation, scale, target location, etc. as a function of the plant state. A representative visual scene generated by the graphics or sensor imagery generators is selected by the operator line-of-sight orientation as measured by the helmet-mounted sight. Again, the amount of information selected is governed by the instantaneous field-of-view of the helmet-mounted display (typically 30 degrees to 40 degrees). The helmet display electronics receives the selected portion of the symbology and sensor information and displays the video imagery to the operator through the helmet display optics in the proper orientation within three-dimensional space. For an airborne VCASS capability, it is only necessary to install the VCS components along with a small airborne general purpose computer in a suitable aircraft and interface a representative programmable symbol generator to an on-board attitude reference system in order to synthesize either airborne or ground targets. This approach has the ultimate flexibility of utilizing the same symbol set, threat dynamics, etc., in the air that were originally used in the ground simulation. In either case, the crew member will engage electronic targets (either air-to-air or air-to-ground) and launch electronic weapons. His performance in these tasks in turn will be recorded and assessed for performance or utilized as training aids for the crew member or operator.

Figure 2 depicts a more advanced configuration of the helmet-mounted sight and display that will be used in the VCASS installation. The helmet-mounted sight and display are integrated into one compact unit that allows a prealigned visually-coupled system package to be easily connected and disconnected from a standard flight helmet. The helmet-mounted sight transducers represented by the STA and SRAH are small and compact and allow a more or less benign mounting in the aircraft cockpit. The side mounted helmet-mounted display is capable of at least a sixty degree field-of-view in this configuration as compared to 30 to 40 degrees for a visor display with a reasonable form factor.

VISUALLY-COUPLED AIRBORNE SYSTEMS SIMULATOR

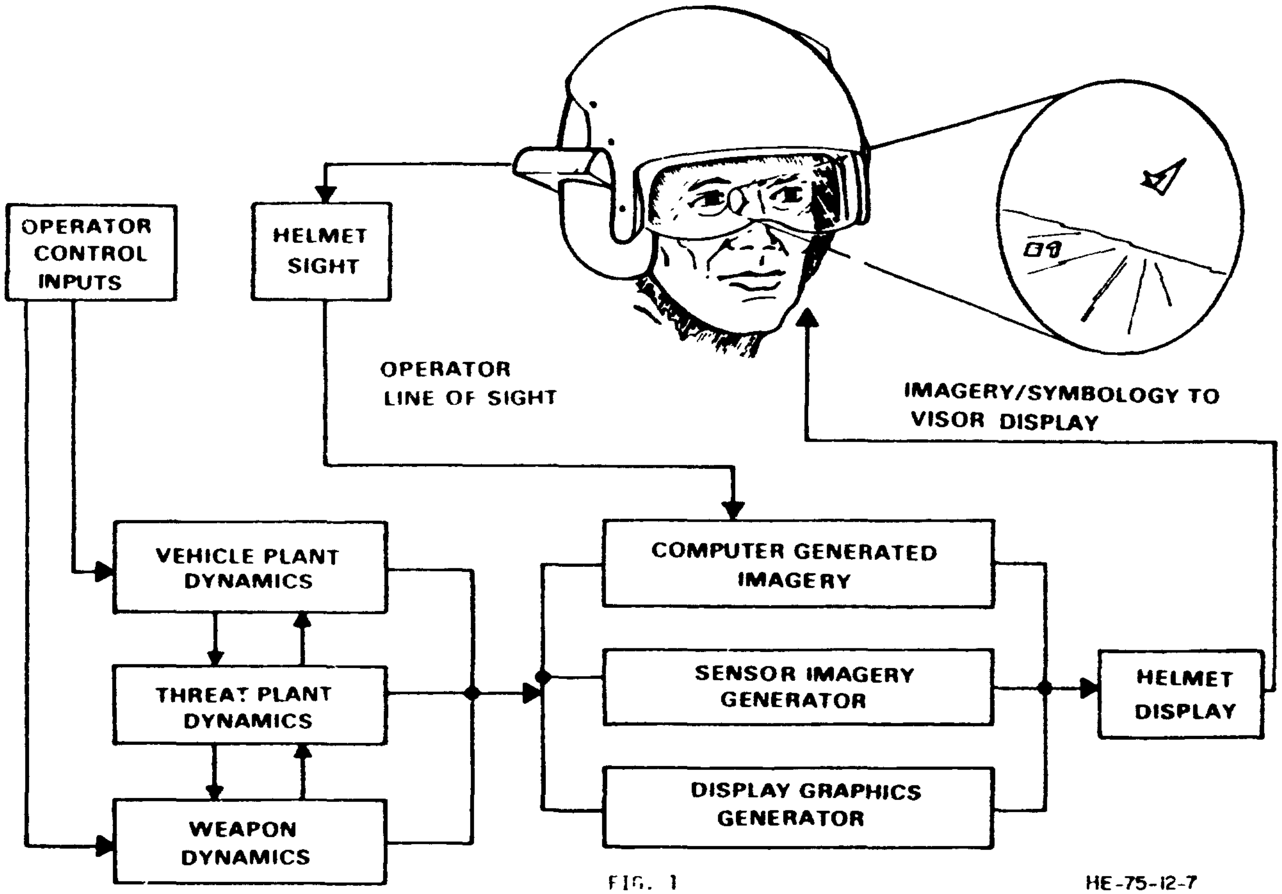


FIG. 1

HE-75-12-7

HELMET MOUNTED DISPLAY —
HELMET MOUNTED SIGHT

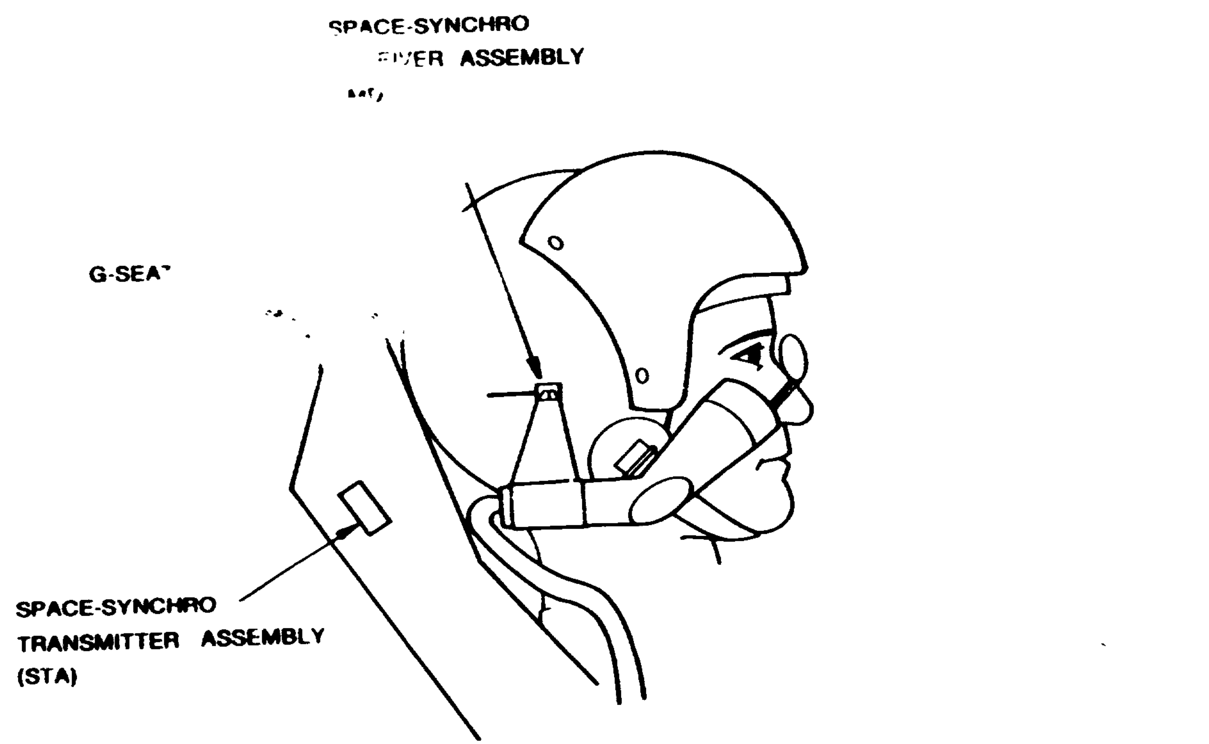


FIG. 2

Compared to other simulation systems this configuration permits a relatively easy transition from the ground to airborne environment for feasibility studies and demonstrations.

The VCASS concept of simulation provides a method of artificially duplicating all the standard scenarios that are provided by more conventional simulators plus more. For air-to-air formats the simulation can take the form of programmed maneuvers as a function of time, evasive maneuvers based on a set of computer algorithms that permit an adaptive strategy for the target, or a totally competitive simulation where the instructor maneuvers the target. For air-to-ground formats the target or threat can be stabilized at prestored ground coordinates, survivability against an active threat can be tested, and target size and vulnerability can be varied. Additionally, visual display design criteria can be developed for fixed base, moving base, and airborne type simulators to investigate and enhance techniques for simulation optimization. Finally, prototype visual display configurations in virtual space can be developed and altered by simply changing the related software.

The cost/performance advantages of the VCASS concept as depicted above appear to be numerous and worthwhile. Of primary importance is the fact that a full hemisphere of collimated visual information can be provided which depends solely on the head orientation limits of the user. This hemisphere of synthesized visual target and environmental images can be accomplished without the need for costly domes or fixed mosaic infinity optics. Conservation of computer capacity is provided as a result of necessitating only the small instantaneous field-of-view of the HMD to be provided to the operator. This suggests that it should be possible to use conventional general purpose computers for computing and creating the environment, vehicle threat and weapon plant dynamics as well as to control a small special purpose symbology generator. The image quality should be very high at the greater luminance levels and color and stereo capabilities are also possible. Also, all threat aircraft and weapon dynamics are programmable providing an ultimate flexibility in design parameters and the cockpit display (HUD symbology sets) can be manipulated easily to determine the interaction between the symbol sets and the synthesized real world imagery. Finally, almost all components including the most critical ones can be utilized in either a ground-based or airborne simulator.

If all the critical components were in an ideal form for the VCASS application it would merely require that one perform the hardware interface, software development, and test the performance obtained out of the final system configuration. However, VCS hardware development and performance has lagged somewhat relative to the performance capabilities of other components that are to be used in the VCASS simulation.

Added to this is the fact that the VCASS simulation imposes certain psychophysical considerations on the entire system configuration. Among the most important of these is the required instantaneous field-of-view of the helmet-mounted display beyond which there will be relatively little improvement in operator performance when flying the VCASS system. The important decisions to be made here are the amount of area on the display that must have a high resolution format and how large the display field-of-view must be to provide necessary information cues in the peripheral vision. Another important requirement is to determine the required update rates and throughput delays to be allowed in the head position sensing information in order to minimize perceptable lags in the change of information on the helmet-mounted display. The symbology and environmental information presented on the display must also change realistically in relation to changes in observer look angle and aircraft parameters in a manner that appears natural with no confusing contradictions. The crew member must be able to relate to aircraft attitude and heading at any look angle. Experience already gained on an interim VCASS configuration has shown that these requirements will necessitate a major symbology and format design effort.

Some of the above mentioned areas of consideration must wait for further testing before a design approach can be formulated while others will not. To some extent the maximum obtainable performance of certain parameters of the most suitable VCS components is already known and must be accepted or its effects reduced by changes to other portions of the VCASS system. For the helmet-mounted sight the individual added requirements are both more easily defined and met than is the case for the helmet-mounted display.

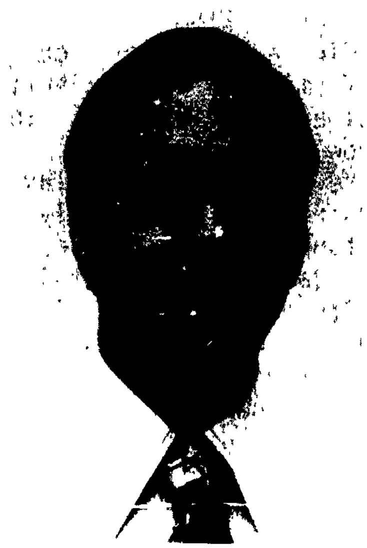
Even though individual requirements for the helmet-mounted sight are straightforward in an engineering sense the total design change package represents a significant increase in performance over systems currently available. To minimize perceptual lags and prevent loss of head movement coverage, the update rate must be increased from the presently available 33Hz to 100Hz or more and the motion box must be enlarged from one to four cubic feet. In order to provide sufficient information to simulate the parallax of aircraft structures on the helmet-mounted display as the operator moves his head, a six-degree-of-freedom HMS is required that provides not only attitude information (azimuth, elevation and roll) but x, y, z position information as well. Another significant problem is the smallest change in head movement which can be measured by the HMS and therefore provide updated information for changing the video imagery on the helmet-mounted display. Preliminary studies have suggested that resolution must be increased from 0.097 to 0.03 degrees to eliminate noticeable step changes in the display presentation as perceived by the observer. Finally, some form of output stabilization must be provided to reduce head jitter noise

from whatever source to an acceptable level that would not visibly degrade display resolution.

The design considerations involved in building a helmet-mounted display for the VCASS simulation present a more formidable and subjective set of problems whose solution is not entirely clear. It is certain that a larger display field-of-view is required but how large remains an unanswered question. The optical physics that are part of the display design imposed constraints which are difficult to resolve. Currently, an interim display possessing a 60 degree instantaneous field-of-view is planned for the VCASS; however, recent studies have shown that this may not be large enough especially when viewed with one eye. This leads naturally to biocular or binocular configurations. A whole host of human factors problems then becomes important including brightness disparity, display registration, and eye dominance. The decision whether or not to include color also becomes a major design decision not only because of the engineering development required but because user acceptance may weigh heavily on this factor.

If the design problems can be overcome it appears that the benefits of the VCASS for training are great. Experience for the crew member can be provided in many aircraft types against a wide variety of threats, armament, encounter dynamics, etc. Feedback in the training situation can be significant and rapid with optional instructor involvement, repetition and instant replay on all encounters, and the fact that an airborne vehicle can use VCASS components to correlate ground-based results. The cost effectiveness of this approach seems to be overwhelming. The cost of this system is assured of being significantly less than the costly ground visual simulators now in existance. One system can be used for the air and ground environment. In the airborne case no darts, drones, chase planes or bombing ranges are required and no aircraft armament installation or expenditure of munitions is needed.

CIG DATA BASE REQUIREMENTS
FOR
FULL MISSION SIMULATION



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DATA BASE REQUIREMENTS FOR FULL MISSION SIMULATION

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I. INTRODUCTION.

In recent years, the Air Force has increased the emphasis on full mission simulation for aircraft crew training. The full mission simulator simulates all aspects of the aircraft and its mission to the aircraft crew members. This full mission simulator is characterized by the Weapon System Trainer (WST).

This emphasis is due to the increasingly more cost effective training which can be accomplished in a WST. Obvious cost savings of full mission simulation over actual aircraft training are that expensive fuel is not consumed and costly weapons are not expended. A less obvious savings is that a pilot can fly more events in the simulator than in an aircraft. In the simulator, there are no restrictions on aircraft time or airspace thus the pilot has more time to train. Another savings with the full mission simulator is the reduction or elimination of non-critical parts of the mission such as flying to the gunnery range, waiting for another aircraft to clear the area, flying out for another approach and landing, etc. These are but a few examples of the cost effectiveness of full mission simulation.

Another reason for emphasis on full mission simulation is to provide training which cannot be effectively flown in the aircraft. Examples of such flight-limited training are flying in hostile environments, emergency war order rehearsal, and safety restrictions on peacetime training.

One of the most important areas of full mission simulation is visual simulation. Only with the recent developments in computer image generation (CIG), has full mission visual simulation become possible. The key features of CIG which permit full mission simulation are:

A. Large area of terrain coverage.

B. Multiple images which can be mosaicked for a large continuous field of view.

C. Unlimited attitude and position.

D. Moving objects, targets, and vehicles.

E. Provisions for additional visual information not available in the real world (such as weapon impacts which remain visible for a period of time).

F. Special effects (such as weather, ground fire, time of day, etc).

Unfortunately, the CIG technology is not yet sufficiently advanced for direct application to all full mission visual simulation. There are several areas in CIG technology which require improvement or development for production systems. One of the prime areas requiring development is the CIG data base modeling techniques.

This paper will primarily address the CIG data base requirements and not the CIG system hardware. Occasionally, hardware requirements will be described for applications which are new or unique.

II. PAST CIG WORK.

The past work in CIG was primarily concerned with hardware development, with only limited work in the area of data bases. Consequently, the early data bases were small, allowing only simulation of limited visual missions. The digital logic and memories were relatively slow and expensive. This slow hardware resulted in an emphasis on hardware design with data base work being neglected. As digital technology improved with higher speed and lower prices, more emphasis could be applied to data base design. In addition, increased edge processing capability permitted more complex missions to be simulated which in turn required significantly larger data bases. The recent emphasis on multi-purpose CIG systems (e.g., sensor simulation) has levied the requirement for data bases many orders of magnitude greater than the processing capability of the hardware. Table 1 lists, in chronological order, the CIG processing and data base capacities of several CIG systems. This table indicates the increasing importance of the data bases.

III. CIG REALISM REQUIREMENTS.

The term "realism" is often used to describe the quality of visual simulation. According to Webster, realism, as applied to visual simulation, is defined as "the theory that art or literature should conform to nature or real life; representation without idealization." Examples of characteristics which contribute toward realistic visual simulation include:

A. Image quality.

B. Exact perspective.

C. Correctly changing perspective.

D. Coordination of all cues (visual, motion, control forces, and instruments).

E. Complete field of view as provided in the aircraft.

F. Unrestricted flight path.

G. Proper brightness and contrast.

H. Correct color.

TABLE 1

EXAMPLES OF INCREASING DATA BASE CAPABILITIES

	SYSTEM	EDGES PROCESSED	LIGHTS PROCESSED	DATA BASE	DELIVERED
1.	NASA II	240	None	240	1967
2.	2F90	512	Edges Used	2,000	Sep 72
3.	ASUPT	2,500	Edges Used	100,000 delivered* 600,000 capacity	Sep 74
4.	2B35	1,000	1,000	10,000 edges 1,000 lights	Sep 75
5.	AWAVS	1,000	2,000	10,000 edges 2,000 lights	1977
6.	B-52 EVS	2,000	4,000	Sufficient number of edges for 250,000 square miles	1980 - 1981

*ASUPT was designed as a research device.

For visual simulation to provide positive training, the pilot must be able to perceive and use the same basic visual cue information in the generated visual scene as he does in the aircraft. All the above listed parameters (and probably more) are required to provide the necessary visual cues to the pilot.

With the exception of image quality, current CIG systems (with an appropriate display) provide all of the above parameters. Image quality is a function of many factors, including image content and image detail. Image content is a measure of the number of features in the visual scene such as buildings, roads, rivers, mountains, etc. Image detail is the "fineness" or "minuteness" with which the features are described in the visual scene, such as tire marks on the runway, vegetation, textures, etc. The imagery for current CIG systems is limited in image content and image detail when compared to the real world. Substantial improvements are required in both CIG hardware and data bases for image quality approaching the real world.

Current and near future requirements for CIG realism are sufficient image content and image detail to allow the pilot to perform his tasks in the simulator the same way as in the aircraft, but without real world appearance of the images. The visual cues may be abstract or idealized representation of real world scenes, but should "operate" visually in the same manner as in the aircraft. These abstract visual cues must contain sufficient realism for eye/hand coordination and motor skill development, but need not contain enough realism for perceptual skills such as small target or object recognition and identification. The immediate data base requirements to provide these visual cues are effective ground texture for altitude and velocity cues, and sufficient detail to identify obvious landmarks.

A future realism requirement will be to provide complete real world appearance. The level of realism must provide training in the perceptual skills, such as detection and identification of small objects and targets. In addition, the realism should be sufficient to add a component of fear into simulated visual flight. This fear could be in the form of the closeness of boom during refueling, closeness of the lead aircraft, anti-aircraft firing, etc. The addition of the fear component would add a new dimension to simulator training. Faithful modeling of the real world will require improved modeling of targets, other objects, and terrain. The terrain must include representation of an actual (rather than a generalized) area including elevation changes, appearance, and texture.

IV. DATA BASE REQUIREMENTS FOR TASK RELATED VISUAL CUES.

A full mission simulator involves several tasks requiring out-of-the-cockpit visual cues. These different visual cues levy varying requirements for data bases. Examples of the various tasks are take-off and landing (TO&L), air-to-air combat, air-to-surface weapon delivery, and

low level visual navigation. TO&L requires visual cues for overhead traffic patterns, circling approaches, and straight-in approaches. Circling approaches and overhead traffic patterns require a larger field of view (FOV) than straight-in approaches because the pilot utilizes the side and overhead viewing capability of his aircraft. Data base requirements for TO&L include local navigation information, visual velocity and altitude cues, as well as other aircraft in the traffic pattern.

Air-to-air combat involves some unique visual simulation requirements. These are large FOV, high resolution, and multiple hostile and friendly aircraft. Additional data base requirements for air-to-air include special effects such as afterburner indications, speed brake actuation, weapons firing, weapons in flight and their exhaust trails.

The visual simulation requirements for air-to-surface weapons delivery include a large FOV with a moderately high resolution display. Air-to-surface data base requirements include ground information similar to that of TO&L and special effects. Examples of air-to-surface special effects are multiple moving targets, weapons in flight, ground impacts, ground fire, and flak. Data base target complexes for air-to-surface include both tactical and controlled ranges, or areas with tactical target complexes representing a wartime situation.

Low level navigation (below 500 feet) requires a highly detailed data base representing a large area of coverage. Low level data bases must provide positional information with enough scene detail to produce an authentic confusion factor for the pilot.

V. IR AND LLLTV SIMULATION AND DATA BASE REQUIREMENTS.

CIG simulation of infrared (IR) and low light level television (LLLTV) sensors is similar to the out-the-window visual presentation in some respects. The perspective, priority, and raster artifacts are the same. The main difference between CIG applications for sensor and visual simulation is amount of detail and the way in which the data bases are encoded. IR data bases are encoded in terms of intensity representing temperature and time of day. In LLLTV simulation, the data bases are encoded similar to visual data bases with adjustments to account for the absence of sun and the addition of active light sources. The sensor-peculiar functions are added after the completion of the perspective, priority, and raster calculations.

Data base requirements for IR and LLLTV are similar in many aspects. Both IR and LLLTV characteristics change with time of day, atmospheric conditions, and the seasons. However, for IR, temperature differences on the same object may create a problem. If a temperature gradient is present across the same surface the data base modeling becomes more

difficult. It is desirable to have the capability to include all these effects of sensor simulation in one data base. These effects would be produced by modification of the data base in real-time. Another alternative would be to modify the computed intensities in real-time to produce the desired effects.

VI. DATA BASE CORRELATION WITH RADAR AND OTHER SENSORS.

Visual data base correlation with radar and other sensors is an important data base requirement. Full mission simulation requires visual simulation correlation with radar, IR, LLLTV, radio/navigation aids, and electronic warfare (EW). Correlation of radar targets, terrain, and other cultural features can be accomplished through separate but similar data bases. The use of common source data for the visual and radar data base generation is desirable. A possibility would be to use Defense Mapping Agency (DMA) digital radar data with similar transformations and then enhance the visual data base for more detail. Correlation of IR and LLLTV with the visual presentation can be accomplished by the same or a similar data base. If the IR or LLLTV sensor has a smaller FOV than the visual system, the sensor simulation could require a more detailed data base. Visual correlation with the radio/navigation aids involves loss of radio signal when shadowed by terrain. In addition to occulting, EW correlation involves presenting similar angular position and range of emitters on the EW cockpit display and out-the-window visual displays. The data base must also correctly correlate with the visual representation of the emitter. Correlation can be provided by developing the visual data base to match the EW data base. Another EW correlation requirement would include matching time sequences for missile launch or other weapon activation with the other simulated systems. Various types of moving targets must also be correlated with the visual. FW processing for altitude and target dynamics may need to be increased for more faithful simulation of moving targets.

VII. SMART WEAPONS SIMULATION.

New weapons have been and are being developed which use a television, IR sensor or laser for guidance. Each of these guidance methods require the pilot to align the seeker head on the target. With the IR and television camera guidance systems, there is a small television monitor in the cockpit on which the pilot views the camera or IR sensor imagery. Lock-on is accomplished by placing the target under the range gate presented on the television screen by either moving the aircraft or using a cockpit control and then actuating a cockpit switch. The IR sensor simulation requirements will be similar to those discussed earlier. In all cases, the simulation of lock-on problems is necessary for full mission simulation. The data base requirement for simulation of these "smart" weapons is the same or similar to the visual or sensor simulation data bases and must be correlated.

VIII. COMMUNALITY BETWEEN SYSTEMS.

As the Air Force procures more CIG systems, it is desirable that the data bases be compatible. This compatibility requires data bases generated by one contractor to operate on a CIG system manufactured by another contractor. Commonality in CIG data bases would reduce data base development costs, especially with large gaming area requirements. A less desirable alternative to data base commonality would be a flexible data base which could be transformed into the proper form for other system data bases.

IX. DEFENSE MAPPING AGENCY (DMA) DATA.

The large area of coverage of CIG visual and sensor simulation has introduced the requirement for a large area source data such as that provided for radar by DMA. It may be possible to perform a transformation on the DMA source data to produce the required CIG data bases. Since DMA source data contains only terrain and radar significant information, enhancement of the resultant transformation will be necessary for certain high detail requirements. This approach will be described in more detail in the paper entitled Computer Image Generation Using the Defense Mapping Agency Digital Data Base, by Hoog and Stengel, later in this conference.

X. DATA BASE MODELING.

Data base modeling is the subject of growing concern to the simulation community in the Air Force. This concern stems from the need for quick modifications at the simulator training site. Also the high data base development costs has made an in-house capability imperative.

The earlier CIG systems provided a very basic modeling capability. All changes were manually inserted and required a considerable amount of time. After the changes were entered, the entire data base had to be recompiled. These systems had no interactive capability and in order to verify the changes the real-time state had to be entered.

Future requirements for data base modeling will involve an interactive system with capabilities to simplify the modeling task. One such simplification would be the availability of an object library. This library should consist of common object definitions such as mountains, roads, rivers, air base structures, etc. The modeling software should use a conversational language which will result in a compilation of the added or changed objects only. The compiler's output should be automatically merged into the existing data base and graphically displayed on a CRT for inspection by the modeler. The compiler should perform basic error detection functions on the modeler's input data and produce an error listing. This interactive capability will allow a modeler to verify objects in the environment at different locations and attitudes to determine correct placement.

XI. CONCLUSIONS.

The Air Force currently has two engineering developments underway for improving CIG data base technology. The projects are the Electro-Optical Viewing System (EVS) simulation for the B-52/KC-135 WST and Project 2360, Fighter/Attack Simulator Visual System (FASVS). The EVS on the B-52 aircraft consists of steerable IR and LLLTV sensors with viewing monitors for the flight crew. These sensors are used whenever the flash shields are placed in the B-52 windows, and in conjunction with radar, for terrain avoidance and bomb damage assessment.

The simulated EVS imagery will be generated by a CIG system shared with the visual. The data base requirements for the EVS simulation is for an extremely large area of terrain coverage for both IR and LLLTV sensors. The specific data base developments on this program are implementing the large data base, a transformation program to convert DMA digitized data into the CIG EVS data base, and the capability for quick updates to the data base. This engineering development program is a part of a "head-to-head" competition with contracts negotiated with the Boeing Wichita Company and Link Division.

Project 2360 is an engineering development project to develop a generic visual simulation system for fighter/attack aircraft. The production units are currently scheduled to be integrated with the A-10 and F-16 TFS manufactured on separate contracts. The FASVS will be designed for full simulation of the air-to-air combat and air-to-surface weapon delivery missions. A portion of the development effort will be in the data base. Specific data base features include:

A. Sufficient detail to perform low level navigation.

B. Special effects for air-to-air combat.

C. Special effects for air-to-surface weapon delivery.

D. Expansion capability for smart weapon delivery and sensor simulation.

The anticipated release of the Project 2360 RFP is June 1977.

The above engineering development efforts are being sponsored by the Air Force. However, there are development areas which are appropriate for industry to take more of the initiative. These areas are improved CIG realism through better data modeling techniques and improved methods of data base generation. Realism is a parameter which is difficult to quantify and is often dependent on the contractor's approach to CIG. The generation of data bases is also dependent on the contractor's approach to CIG. And, again at this time, it appears that the CIG manufacturers should take the initiative to design and develop efficient, and easy to operate data base generation systems.

Other data base requirements, which are just surfacing include the use of transformed DMA data for visual simulation and commonality of data bases between CIG manufacturers. At this time, it appears that the Air Force will initiate the developments to produce the technology to meet these requirements.

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SIGNIFICANT NON-TARGET EFFECTS
ON
TARGET ACQUISITION PERFORMANCE

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SIGNIFICANT NON-TARGET EFFECTS ON TARGET ACQUISITION PERFORMANCE

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I. BACKGROUND OF THE PROBLEM

Visual acquisition of vehicle-sized targets* in the field from the air has occurred at average ranges varying from 900 ft. (C.G. Moler) ** to five miles (Erickson and Gordon) in published studies. Fixed target performance is equally variable. Clearly, the size and shape of the target is not the most significant factor in acquisition performance. If simulation using computer-generated imagery is to replicate "real world" performance, the non-target factors must be identified and, if truly significant, simulated.

A series of studies (field, simulator and literature) over the past 10 years at Autonetics and elsewhere has provided some insight into the sources of performance variation. Much of this work is summarized in Greening (1974). Several sources of variation are, while not strictly target-related, dependent upon the target-plus-setting; these will be discussed, with quantitative data where available.

II. BRIEF REVIEW OF AIR-TO-GROUND ACQUISITION

Visual search and detection of targets over land is far more complex than the typical laboratory search experiment. The environment in which the target lies provides, at times, both negative effects (e.g., masking, confusing non-target objects, contrast reduction) and positive ones (e.g., dust plumes, helpful patterns of roads and streams). These effects interact with other, non-visual effects such as training, stress, and briefing instructions.

* "Target" is used here in the generic sense as "the object of a search." It is not limited to objects of attack.

** References are listed, alphabetically by author, at the end of the paper.

In spite of the potential complexity of the task, a number of events usually takes place during a target acquisition sequence (though certain steps may be omitted and loops may occur in some circumstances):

1. Instructions and/or briefing prior to the mission (what am I looking for? what is known about it?)

2. Maintaining orientation with respect to the terrain (where am I relative to the search area?)

3. Search (may be along a road, or anything in a general area; may be looking for a special target, at a known location, or for "anything of military significance")

4. Detection (of something, possibly target-associated)

5. Recognition/Identification (is it target-related? is it a target? or is it just a confusing object?)

III. IMAGERY-RELATED EFFECTS

The relationship between the elements of target acquisition and the imagery provided in a simulator is more evident in some parts of the sequence than others.

1. Instruction

   In addition to briefing on the target itself, the target or target class is often described to the observer relative to terrain features. "Bridges" are usually found where roads and streams intersect. SAM sites in forested areas will be located in clearings. Trucks will be found on or near roads. These features of the terrain are, then, a significant part of the target/surround situation.

2. Orientation

   If a target or target class is expected to be in a specified map location, the observer must be able to relate the terrain to the map. But he may spend valuable time trying to remain oriented. Large-scale terrain features are often crucial here.

3. Search

   The speed and effectiveness of a search is impacted by terrain roughness, vegetative cover, natural or man-made "grids" to guide search, atmospheric properties, direction of illumination.

4. Detection

   Targets cannot be detected unless a clear line of sight exists, and contrast is adequate. Chances of detection decrease as the number of confusing forms or "clutter" increases.

5. Recognition/Identification

   Features which distinguish targets from other objects must be visible if correct decisions are to be made. Not all such features are part of the target itself. If significant, they need to be simulated.

From a consideration of these imagery-related effects on target acquisition, a list of relevant imagery characteristics can be drawn up:

1. Meaningful, unique large-scale features, relatable to maps.

2. Terrain and foliage masking, including partial obscuration.

3. Road networks, rail lines, streams in natural relationships.

4. Confusing objects of a variety of kinds, sizes, densities.

5. Indicators (such as dust plumes, mudholes, glint, motion).

6. Contrast reduction related to range and sun angle.

Whether these characteristics must be represented in computer-generated imagery will depend upon (a) whether they have significant effects on performance, and (b) whether the effects are of concern in a particular simulation. The second part of the question must be answered by the user; the first part will be considered in the next section.

IV. QUANTITATIVE DATA ON EFFECTS

A. Navigation and Orientation

Maintaining orientation relative to map location and target area is difficult, especially at low altitudes. One set of nearly 1,000 simulated combat missions flown out of a California air base was studied intensively by McGrath and Borden (1964). Approximately 25 percent of the missions were compromised or aborted because the pilots became lost. In a careful, cinematic simulation of similar missions, ground plots of "real" position were compared with navigator plots, with results as shown in Figure 1.

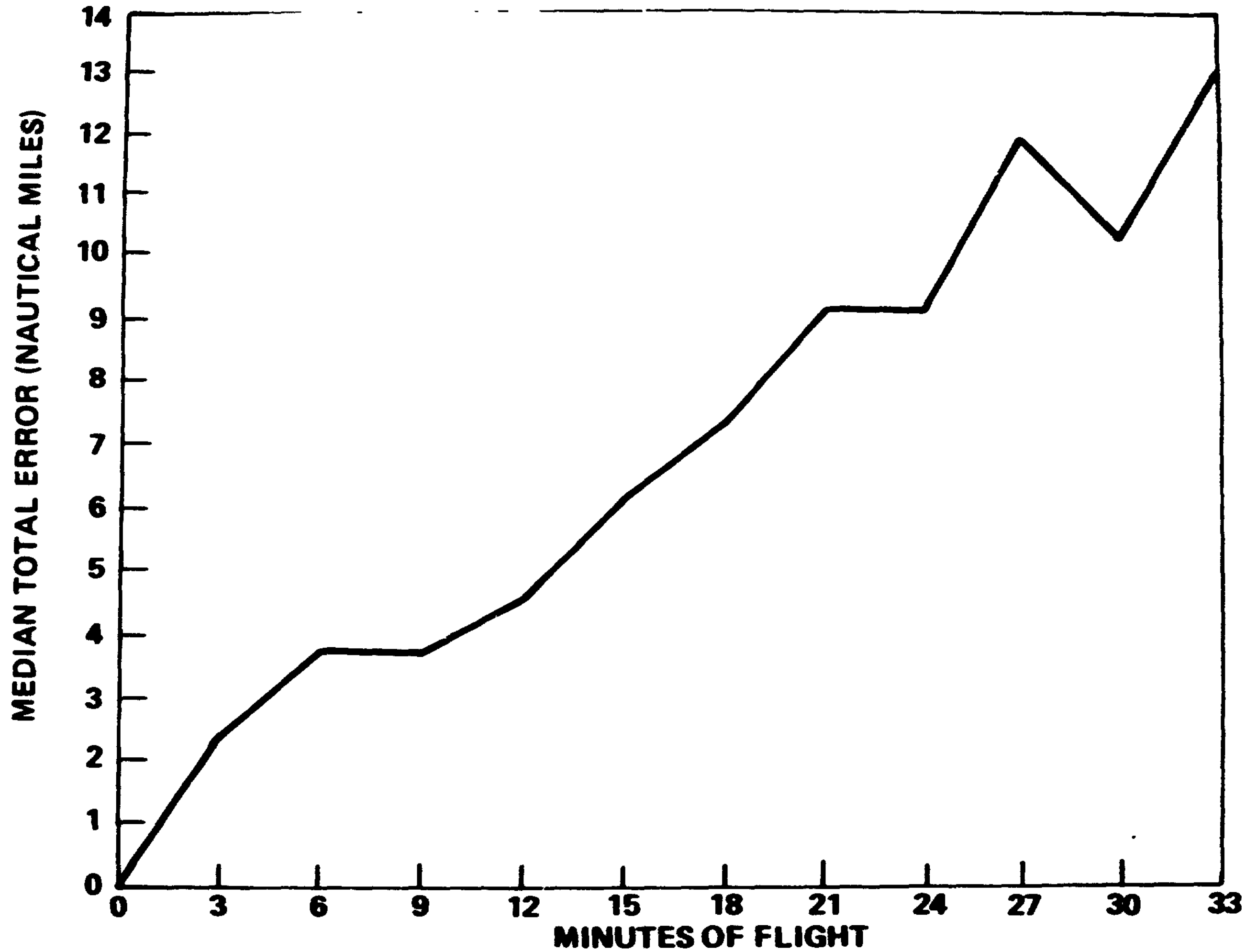

Figure 1. Navigation error during flight (Data from McGrath and Borden)

Missed or mis-identified checkpoints were cited as the cause of disorientation by 40 percent of the disoriented pilots. Later studies in the same series showed performance to be related to the "checkpoint richness" of the terrain, as well as to certain properties of the navigation charts being used.

B. Terrain and Foliage Masking

Terrain masking is geometrically extremely simple - either a line of sight to the target exists, or it doesn't. The statistics of masking with respect to distance and altitude, however, are somewhat more complex. Erickson (1961) has studied terrain masking properties empirically in the California desert. Similar data exist on a number of other kinds of terrain (e.g., Schaefer, 1968). Different parts of the world differ substantially in average slope, typical spacing of hills/ridges, and typical elevation difference between highs and lows, all of which affect target acquisition performance. There have been several attempts to classify terrain on a quantitative basis (e.g., Anstey, 1970).

Foliage masking exhibits an added complexity - namely, degree of obscuration. In wooded terrain, the most typical view of a moderate-sized target is a partially obscured one. Clare (1973) has done a pioneering study on the effects of partial obscuration of vehicles by brush. The results, while showing substantial impact on performance, defy simple representation.

In a different kind of study (USA CDEC), participants in field exercises were asked to rate several potential obscuring effects, with the results shown below. In this study, foliage was judged to have a powerful effect.

MAGNITUDE OF EFFECT	DUST	HILL SHADOW	FOLIAGE	TERRAIN
NONE OR SLIGHT	96%	82%	38%	62%
MODERATE OR EXTREME	4%	18%	62%	38%

Table 1. Effect of masking on target acquisition (Data from USA CDEC)

C. Terrain Features As Target Indicators

Fixed targets in known locations are most often found by reference to terrain indicators. La Porte and Calhoun (1966), in a cinematic simulation study, classified 4600 responses to a "forced designation" task. In this simulation the "flight" was stopped at intervals before target fly-over, and the observer was asked to give his best estimate of target location, the clues used, and his confidence in the identification. Overall, 63% of the clues were non-target indicators. (See Figure 2 for a sample response sheet.) Roads were the most frequently used indicators. The general findings have been corroborated by a more recent British study (Mitchell, 1972).

D. Target-related Clues

In field studies, target-associated features other than the obvious geometric properties (e.g., size, shape) often turn out to be of substantial importance. Simons (1967) has summarized some of these cues, based on experience in Southeast Asia. In a field exercise using helicopter crews searching for vehicles (USA CDEC), observers were asked to rank a number of indicators in terms of utility, with the results below.

REPORTED UTILITY	DUST FROM TARGET	MOVE-MENT	SIZE	GLINT	COLOR CONTRAST	TARGET SHADOW
"NO HELP" OR "SLIGHT"	76%	41%	50%	87%	58%	92%
"MODERATE" OR "EXTREME"	24%	58%	50%	13%	42%	8%

Table 2. Utility of target indications
(Data from USA CDEC)

TARGET NO. 8

TARGET DESIGNATION SHEET

STOP NUMBER	TARGET LOCATION	CONFIDENCE LEVEL	CLUES
A	3E	+++ ++ + - -- ---	HAS CURVE IN ROAD NO CURVES IN BRIEFING PICTURE
B	1A	+++ ++ + - -- ---	THAT'S A HILL. THINK ON OTHER SIDE OF HILL
C	2B	+++ ++ + - -- ---	CURVES IN ROAD PICTURE NO HAS CURVES
D	1A	+++ ++ + - -- ---	ROADS STRAIGHTEN OUT IN THAT DIRECTION
E	1A	+++ ++ + - -- ---	END OF MOUNTAIN
F	1AB	+++ ++ + - -- ---	START OF VALLEY WHITE HOUSES STRAIGHT ROADS
G	12 BC	+++ ++ + - -- ---	CURVES IN LITTLE ROADS

Figure 2. Target Designation Sheet

A terrain-simulator test of a specific indicator - muzzle flash from AAA - showed a significant, positive effect on detection at the higher of two altitudes, but the validity of the simulation is in some doubt (Hilgendorf and Erickson, 1975).

E. Confusing Objects and Clutter

Two different effects arise from the presence of non-target objects in the search field. If the objects in the field (or some of them) are roughly target-like in appearance, they will appear as "candidates" in the peripheral field of the eye, and will have to be fixated in order to make a determination. In this case, performance can be related to the number of such objects in the search field. Simulation data, using aerial photos in areas of varying density of confusing objects, show strong effects (Nygaard, et al, 1964). The data have been plotted against time (Figure 3), and re-plotted together with Boynton's data (1955, -7 and -8), (Figure 4) as a function of number of objects. The "real world" data fall reasonably close to the much more abstract laboratory findings of Boynton.

If the search field is cluttered, but not with objects similar to targets, the effects on target acquisition are much less orderly. If the clutter is small and regular in scale, it may be seen as a background texture, having little effect on target search. For the more usual, chaotic real world situation, all that can be said with some certainty is that cluttered fields are harder to search than plain ones. Data from a field test (Valentine, 1972) and a photo simulation (Scanlan, 1976) show effects in the expected direction, but are difficult to relate to measurable properties of the terrain.

F. Atmospheric Effects

The most common effect of atmosphere on the air-to-ground search is the reduction of apparent contrast of objects at a distance. The impact upon maximum performance range is predictable - even large, clear-cut targets won't be seen if contrast falls below 1 or 2 percent. The effect of less extreme contrast reduction has been documented in many laboratory studies, but is a difficult variable to control in field tests. The physics of the atmospheric effect on contrast are well known in terms of "ideal" properties (such as scattering and absorption of light by uniform layers), but prediction is difficult when inhomogeneities occur. An example of the complexity of the atmosphere/range effects is shown in Figure 5, from Bradley (1974).

A commonplace, but rarely tested, atmospheric effect is the presence of broken clouds. One careful simulation study with photographic imagery and artificial "clouds" was performed by Rockwell International some years ago (Levy, G.W. and Weiler, E.M., 1964). The results of varying degrees of obscuration upon the task of map orientation (<u>not</u> target acquisition,

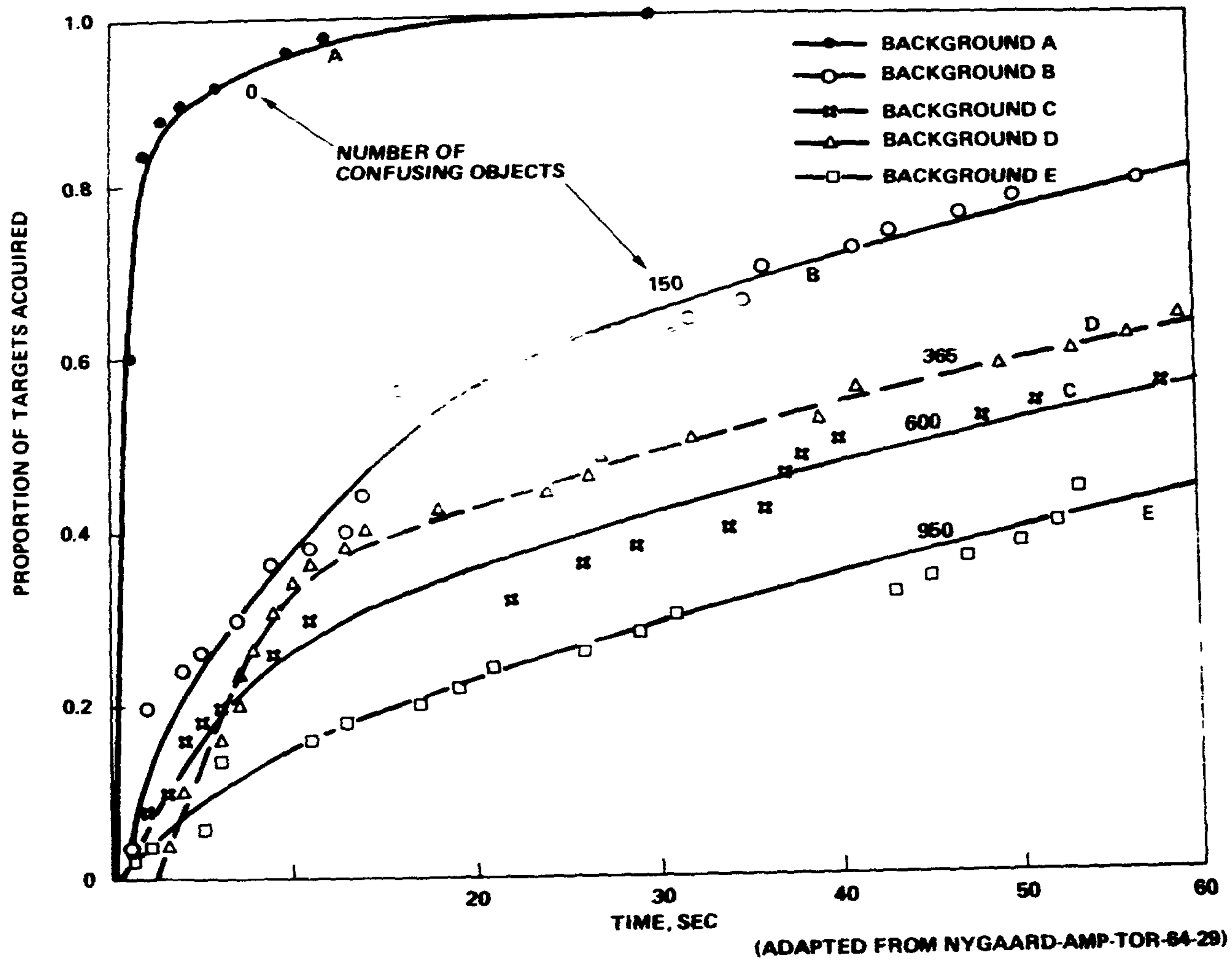

Figure 3. Target acquisition as a function of time for different backgrounds

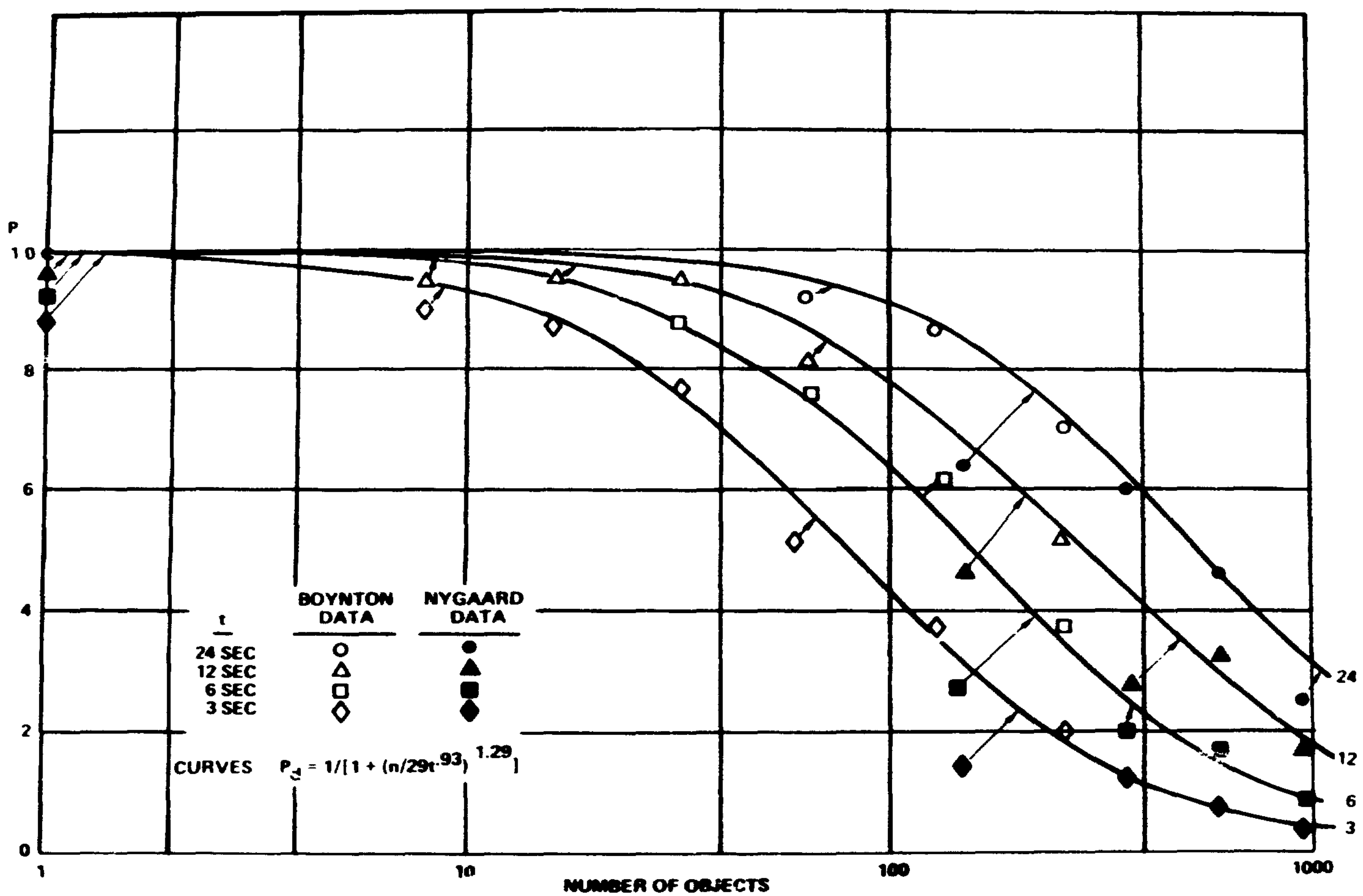

Figure 4. Probability of acquisition as a function of number of confusing objects

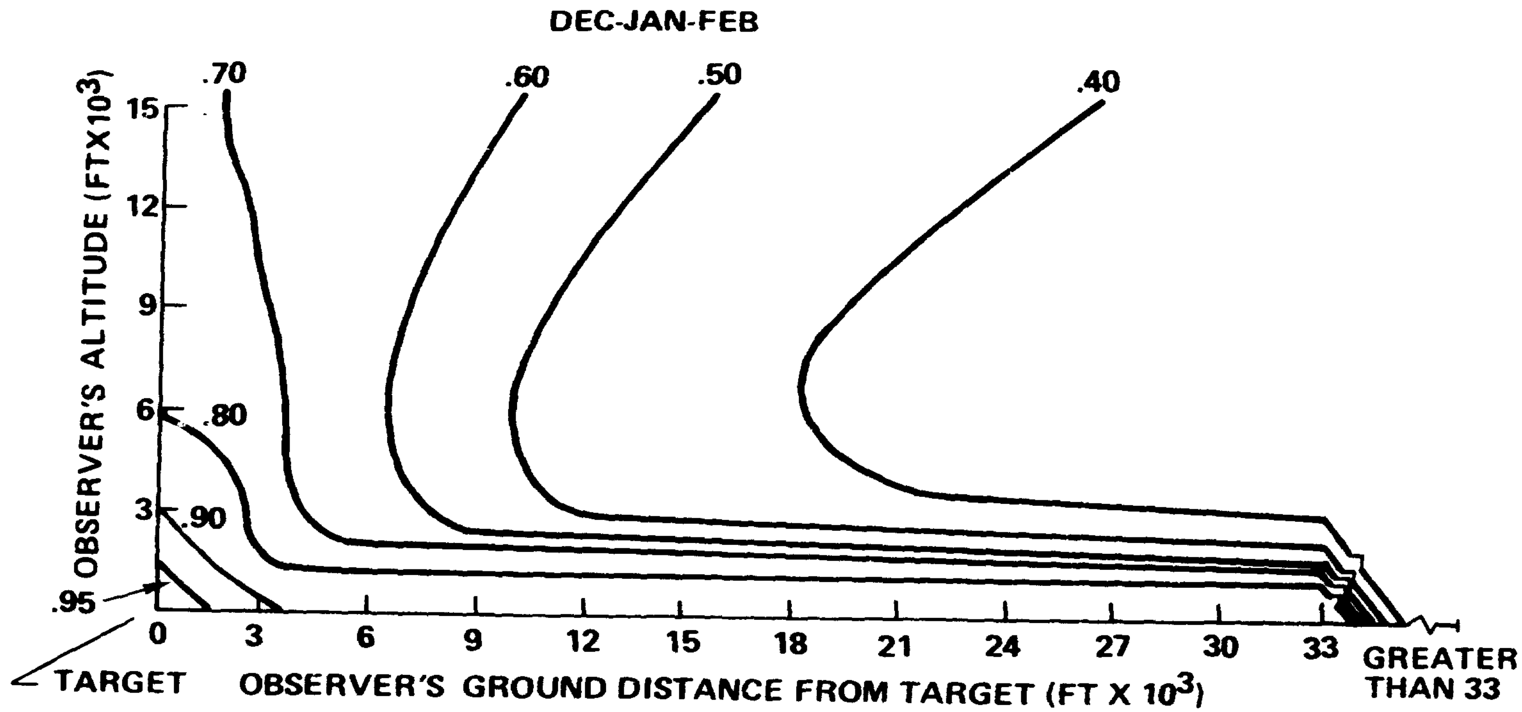

Figure 5. Probability of Penetrable Optical Path for Weisbaden, Germany (from Bradley)

but certainly relevant to it) were as shown.

PERCENT CLOUD COVER:	0	40%	60%	80%
TIME TO ORIENT (SEC)	31	50	58	71
PROBABILITY OF CORRECT ORIENTATION:	.88	.79	.70	.50

Table 3. Effect of partial cloud cover on orientation (Data from Levy and Weiler)

V. IMPLICATIONS FOR SIMULATION

The gist of the data reviewed here seems to be that, under some circumstances, search for objects on the ground is seriously affected by an assortment of effects which are only indirectly related to the target itself, and which are difficult to describe at all, let alone quantify and simulate. The most generally powerful effects are those related to: (1) the clutter and pattern of the terrain and its natural and man-made features, (2) the atmosphere and its effect on contrast, and (3) masking and obscuration by terrain and (for small targets) foliage.

Of these three, the atmosphere can most readily be described and simulated, on the assumption of good mixing and simple layering. Several references, such as Bradley (1974) describe the effects on perceived contrast quantitatively.

Masking by terrain is manageable, given an adequate representation of terrain features in the model For "real" terrain, the data can be taken from detailed maps; for abstract terrain, the problem of classification and parameter selection is more difficult but not impossible.

Foliage can be handled, given certain simplifying assumptions. For forest areas, a "false" terrain surface at mean tree height should suffice.

Ryll (1962) discusses a number of options for more detailed representation, if needed. Fine-grain foliage effects (such as partial screening by bushes) appear to have serious effects on performance, but will be very difficult to simulate.

Ground pattern and clutter can also be divided into sub-classes. Large scale, natural and man-made features can be simulated from map data, though care must be given to the way in which roads and structures "sit" in the terrain, especially in old settlements. Smaller features, too small and numerous to be mapped and constructed (e.g., bushes, puddles, shadows), would have to be represented by classes of small shapes with varying statistics and descriptive parameters. An adequate source of descriptors is not known to the author.

In all the effects described here, the test of adequacy of representation should be the effect on performance, validated against meaningful field data. As we have seen, unambiguous data on individual effects are not easily found.

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LIGHT SIZE AND PERCEPTION OF GLIDE SLOPE IN COMPUTER GENERATED VISUAL SCENES

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LIGHT SIZE AND PERCEPTION OF GLIDE SLOPE IN COMPUTER GENERATED VISUAL SCENES

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INTRODUCTION

Night scenes are included in most computer generated image systems used for flight crew training. Because of resolution limits in such systems, lights usually do not shrink properly with distance. The criterion for representation is that lights should appear in the simulator as they would appear in the real-world situation. In the physical world, a 4 inch light subtends about 10 arc minutes at 100 feet, 1 arc minute at 1000 feet, and 0.1 arc minute at 10,000 feet. However, the optical characteristics of the eye set a lower limit on the smallest size that must be represented. For example, at scene luminances comparable to what might be provided in such an image system, the light from a true point source will be spread over about 1-1/4 arc minutes on the retina. Depictions of smaller size are probably not warranted.

Representations of Point Sources in CGI Systems

The General Electric Compuscene, as made for the Boeing Company, has a built in model which controls the size of lights when the aircraft is within 1000 to 100 feet of the light. Beyond 1000 feet, a random 11% of the lights are at 2.47 x 2.87 arc minutes, 45% are 2.47 x 5.6 arc minutes and the last 44% are represented at 9.6 arc minutes.

The minimum size represented by one active TV line and one segment of that line is the smallest visual angle represented above. It is the horizontal and vertical smoothing routine that creates the two larger sizes from the minimum light source size in the G.E. system. In Figure 1 the G.E. system is represented as the CGI curve 3. The expansion of the lights for the distances of 1000 feet to 100 feet is illustrated. This increase in size as a function of distance assists, we believe, in the perception of relative speeds especially during the slower speeds during taxi and takeoff. The only other day/night scene using a TV line scan display is depicted (CGI #5) as having 8.5 arc minutes light sizes. These values are theoretical and were provided the authors by Lufthansa. All other sizes were measured with a theodolite located at the pilot's eye reference point in the virtual image systems. Measurements on the beam penetration CRT systems were made operational and demonstration displays through the courtesy of United Airlines and McDonnell Douglas. The measured size differences among these systems may be in part due to equipment design differences, but probably, are more directly a function of the luminance level of the display at the

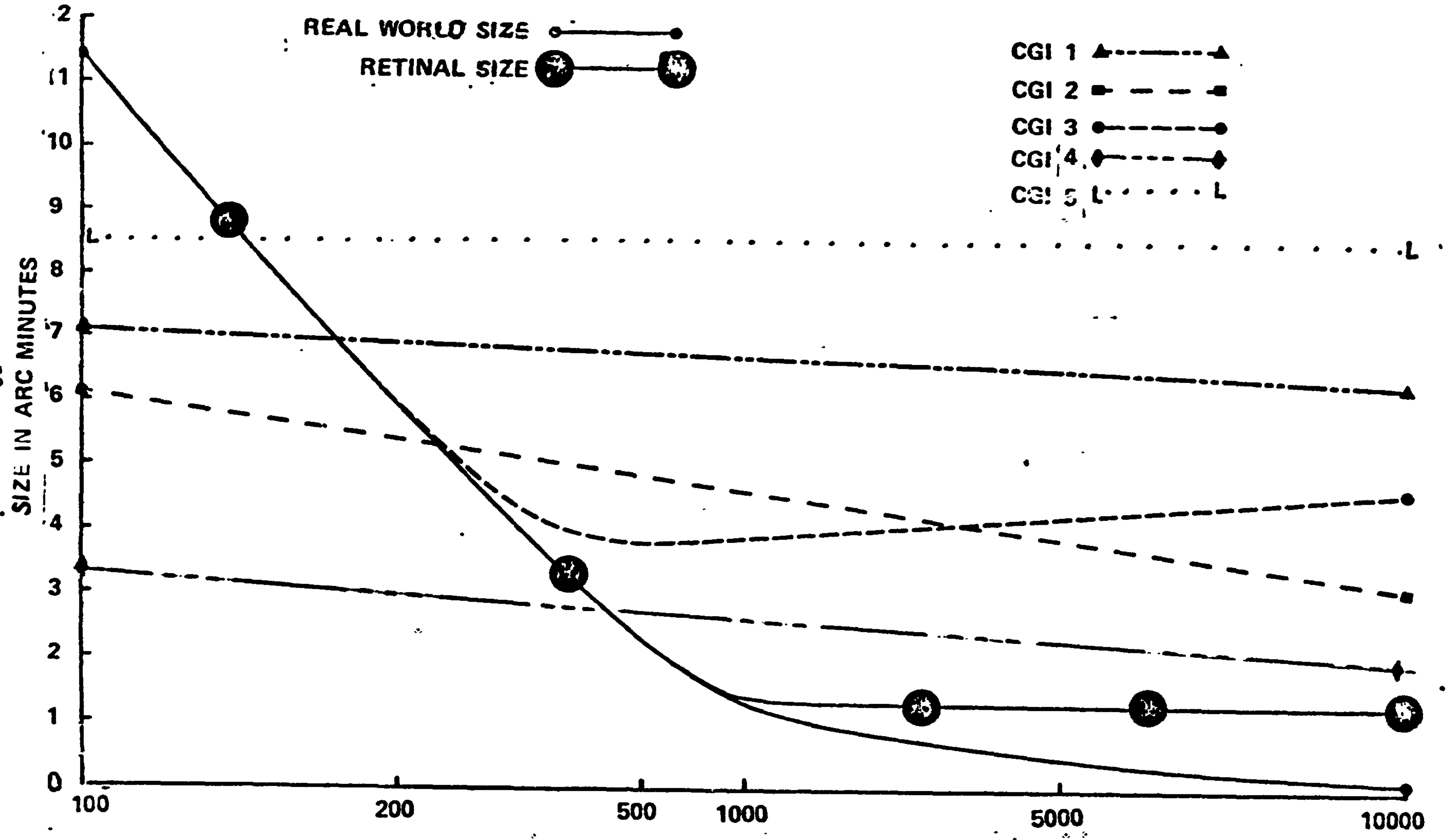

FIG 1. REPRESENTATION OF LIGHT SIZES IN NIGHT SCENE

time of the measurement. It was not feasible to accurately measure the luminance at the same time the size measurements were taken, but the apparent luminance was lower in those systems depicting the smaller point source size. The range of luminances in this figure is from the 6 foot Lambert (ft.L.) luminance of the G.E. system to 0.2 ft.L. of one of the beam penetration CRT systems.

Since no computer generated image can depict the full range of real world light sizes, it is suggested that such systems should have a routine of rolling off the luminance of these lights as a function of greater depicted distance. Such an luminance attentuation as a function of distance should be representative of the real world atmospheric (clear air) attenuation. In addition, a further decrease in luminance should be added to compensate for the excessive size representation of the more distant lights.

Although the above theoretically is a logical assumption we do not know whether it has an actual impact on pilot performance when flying to the night scene in the simulator. However the adequacy of training with night scenes, the validity of transfer of training and future air safety may rest with the answer. This study is an initial attempt to provide part of the answer. It is a portion of the continuing effort of Flight Crew Training*, Boeing Commercial Airplane Company, to improve their visual system and flight training with this aid.

THE PROBLEM

- To determine whether pilot performance in making night visual approaches and landings differ when: (1) Scenes are composed of lights of equal luminance. (2) Scenes are composed of light attenuated in luminous intensity to compensate for atmospheric attenuation and for excessive depicted size.

- To determine whether the relative visibility of runway texture modifies the differences in pilot performance.

- To determine whether the dynamics of a CGI system would provide sufficient visual information to compensate for incorrect light size and luminance attenuation in CGI systems.

- To determine whether one combination of visibility of texture and depicted luminance of night scene lights provides a better training situation.

* This organization supported the authors in this work, with engineering and maintenance of equipment, and provided the experienced instructor pilots.

THE METHOD

The study was divided into two major parts; (1) An investigation of static photographic imagery, the operational equivalent of the pilots including the external scene in the pilot's scan pattern. (2) An investigation using the dynamic CGI imagery in the operational equivalent of making a descent/approach to a runway.

The Static Imagery Tests

The static imagery consisted of 75 photographs taken of the CGI (Compuscene) night scene of a 13,500 ft. runway whose width was 300 ft. between lights. The moonlit scene with various combinations of runway edge lights, approach lights, and runway texture. Twenty-five of these photographs represented the runway with edge lights and approach lights only. Twenty-five represented the same runway with edge and approach lights plus texture on the surface of the runway and the last twenty-five represented the texture of the runway with no edge lights, but with approach lights. In each of these groups of 25, five different distances were represented and at each of these five distances, five altitudes were represented. The distances were; 0, .4, .9, 1.4 and 1.9 nautical miles from the runway threshold. The altitudes depicted were $\pm$ 1 and 2 dots high and low at each distance (1 dot = 0.35° from 2.5°). One set of photographs represented the scene with equal brightness of lights regardless of distance. In this set the far end of the runway edge lights appeared to run together, appeared brighter, and to some extent appeared elevated with increasing distance (Figure 2).

A second set of 75 photographs was made in exactly the same manner but with lights that were attenuated in brightness as a function of distance and excessive size (Figure 3).

In separate sessions, separated by several weeks, the two sets of photographs were sorted by ten pilots who were asked to sort all 75 photographs by the depicted altitude. Eleven sorting categories were used representing "on glide slope" and one half dot intervals above and below glide slope. The experimental design and apparatus are illustrated in Figure 4. This sorting task was accomplished by the pilots by turning over one photograph at a time, viewing it for one second and then placing it in one of 11 vertically stacked boxes. The center box was labeled "on glide slope" and each of the other boxes were labeled in one half dot steps.

The ten pilots were all experienced instructor pilots averaging about 10,000 hours of jet experience. The task for the pilots was to estimate in a quick glance the height of the depicted position of the aircraft and place the photograph in the corresponding "pigeon hole." Therefore if a photograph was judged 2 dots high, that particular

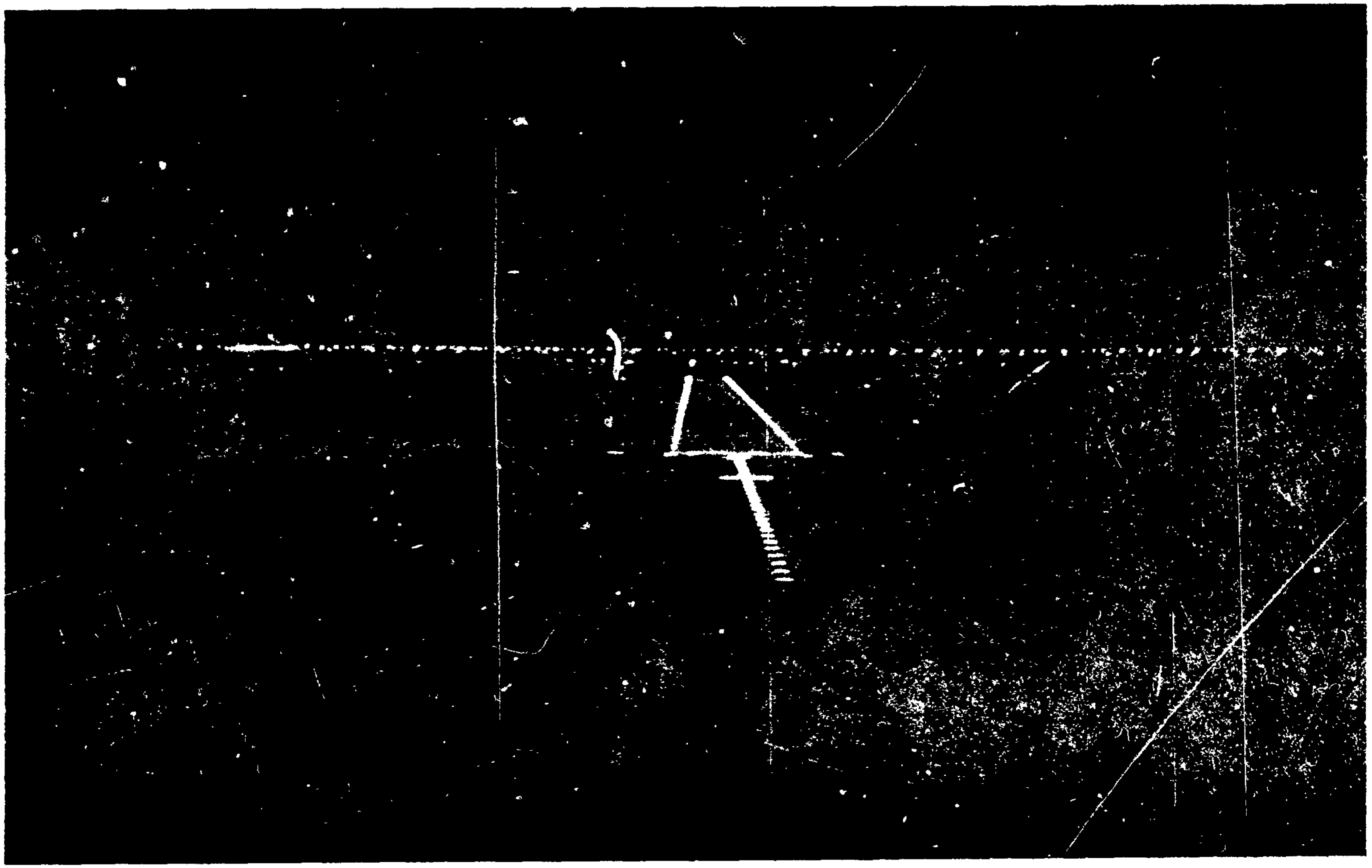

Figure 2   Equal Intensity Lights and Texture

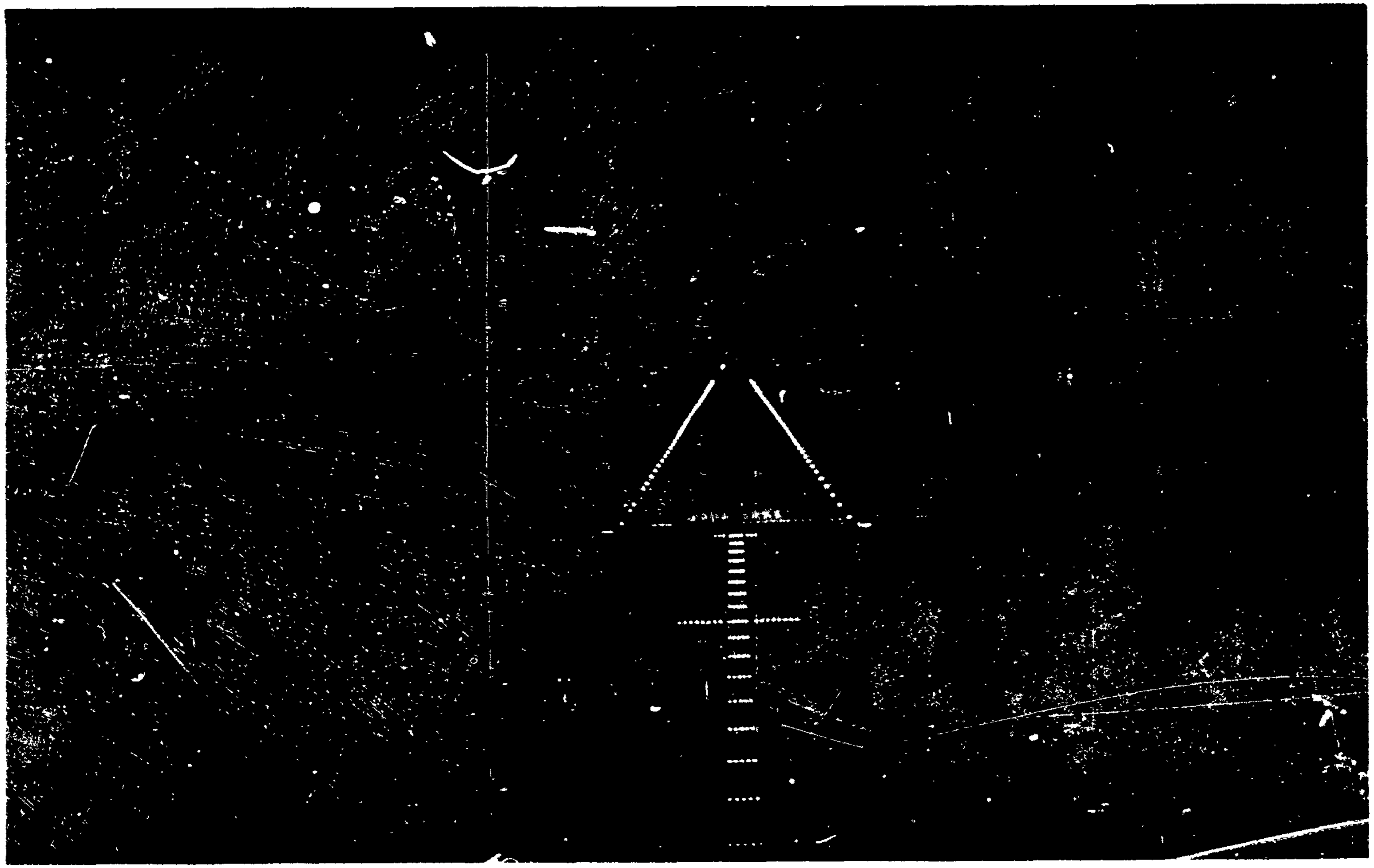

Figure 3   Lights Attenuated as a Function of Distance and Correction for Size.

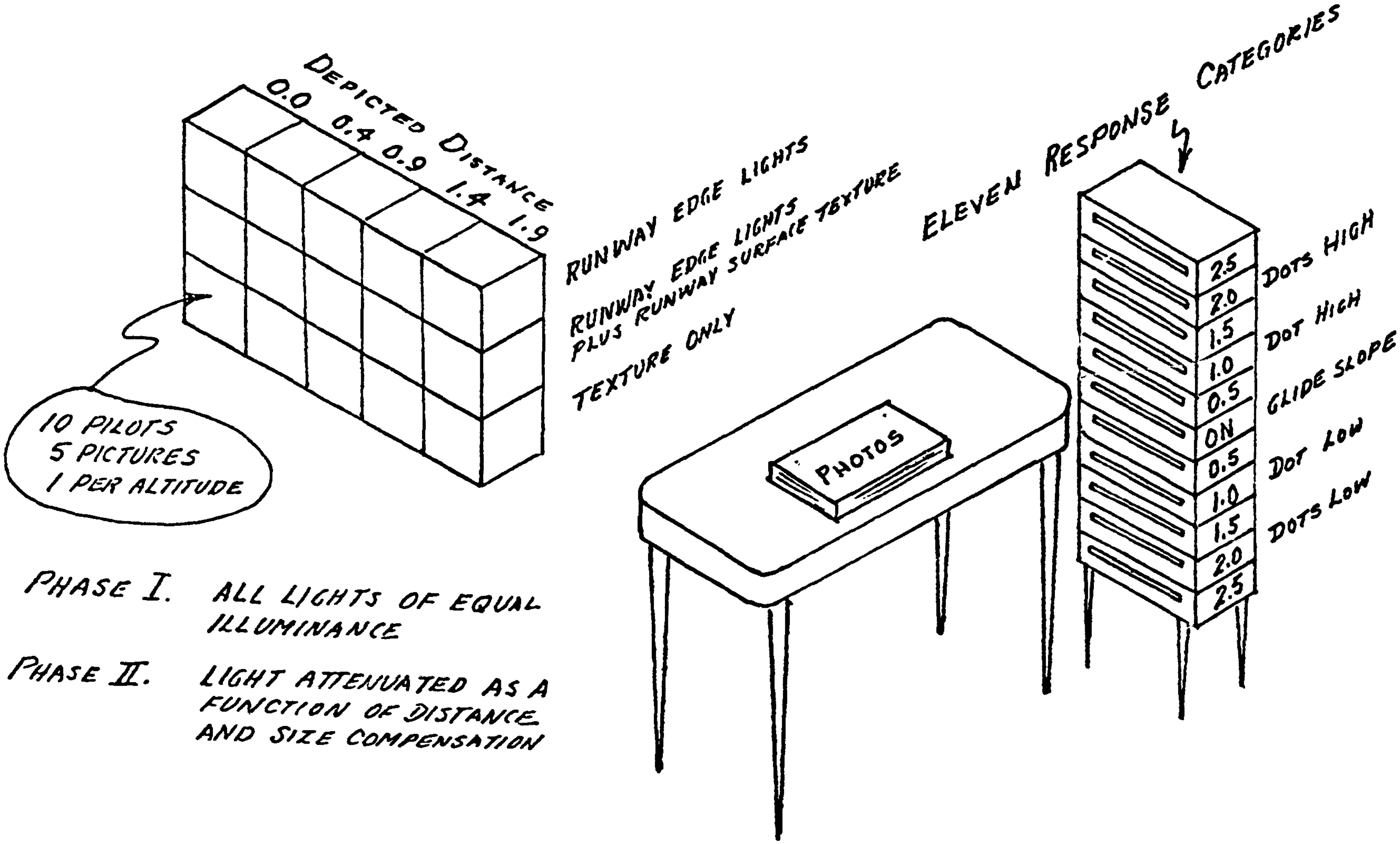

Figure 4 Experimental Diagram Pilots Perception of Glide Slope Position in Night Scenes with Static Imagery.

depiction was scored as adding .7^{o} above the 2.5^{o} glide slope. Two dots low would be scored as 1.8^{o}. After their sorting, the occurrence of photographs in each response category or pigeon hole were scored as the glide slope angle represented by the judgment. The difference between the adjudged glide slope and the actual angle represented was scored as the "number of response steps" error. These data then were treated with an analysis of variance statistic.

The second set of 75 photographs, those with the attenuated lights were judged by a second group of pilots, five of whom had judged the equal luminance series and five who had not made these types of judgments before. The procedure and statistical treatment were duplicated in this instance.

The Dynamic Imagery Test

The General Electric Compuscene, the 727 simulator and the instructor pilots were used in the second portion of the study, to determine whether pilots would generate different approach paths to the two different luminances. In the main experiment, three pilots flew eight letdowns on each of three successive days without the aid of altimetry, glide slope and azimuth indication, or vertical speed indication. In each instance the 727 was initially frozen at 4.7 miles out and on the 2.5^{o} glide slope. The experimental instructor pilot in the right seat took the airplane to an altitude above glide slope and then set up a trimmed aircraft with the proper throttles and pitch setting to continue on a 2.5^{o} glide slope descent. As the simulated aircraft descended through 100 feet above the glide slope, an external digital printer was turned on. The aircraft was released to the observer pilot when the aircraft had further descended to the 2.5^{o} glide slope. The instruction to the pilot was to make a visual approach touching down at the 1000 ft. mark, "as you would with an operational load of passengers," but not to put it on hard just to hit the 1000 ft. mark. He was instructed to fly a normal visual glide slope. At Moses Lake MWH, the electronic glide slope has its origin 1,840 ft. from the runway threshold and so depicts a higher glide slope (a constant 37 feet) than would be maintained if one were on a visual glide slope to the 1000 ft. mark. The pilots were very familiar with this runway.

In each of the sessions, four of the letdowns were with the visual scene lights attenuated as a function of distance and four with a scene in which the lights had an equal brightness regardless of distance. These conditions were counterbalanced on each day for the three pilots. A second independent variable was the relative visibility of the texture on the runway. For session and day 1, the texture became visible at a slant range of 892 feet from the visual touchdown point. On day 2, the texture became visible at a slant

range of 2208 feet from the origin of the visual glide slope and on day 3, 5257 feet from the visual touchdown point. Therefore the order of running and the appearance of the texture is confounded in this experiment (Figure 5).

In preliminary experiments, a group of three very recently qualified 727 instructors had made the same comparison between the two sets of lights with the intermediate runway texture. Following this another set of recently qualified 727 instructors, on a separate day, had made a split half investigation of how they would fly to all the older lights with the same instructions as though they were comparing the new and old lights. Also, in a third preliminary experiment a group of recent 727 qualified instructors repeated the split half investigation with the lights attenuated as a function of distance. In one of the split half experiments the exact control of when the runway texture became visible was unknown, and the second was deliberately set to be visible beyond a nautical mile out. It was apparent from preliminary experiments that this variable had to be controlled to gain reliability in the descent-approaches made with only a visual reference.

A analysis of variance was done with the BMD programs on the IBM computer for the main experiment for the variables of altitude above runway when crossing the threshold, touchdown descent rate and touchdown distance from visual touchdown point (1000 feet from the runway threshold). The differences at any single level of visibility were representative of only 3 pilots. However, the intermediate texture was duplicated in the first preliminary experiment and the intermediate texture condition from the main experiment was treated with a "Students t" without the correlation coefficient.

THE RESULTS

Static Imagery

For the ten pilots, the average perceived height, in the 2.5° and greater glide slope photographs was higher for the equal luminance scenes compared to the attenuated luminance scenes. However, for the scenes of glide slope angles of 2.15° and 1.8°, the perception of height is nearly equal or slightly higher for the attenuated luminance scene. The overall averages were: (See also Figure 6.)

	Texture Only	Texture + Lights	Lights Only
Equal Luminance	2.53°	2.59°	2.62°
Attenuated Luminance	2.52°	2.51°	2.54°

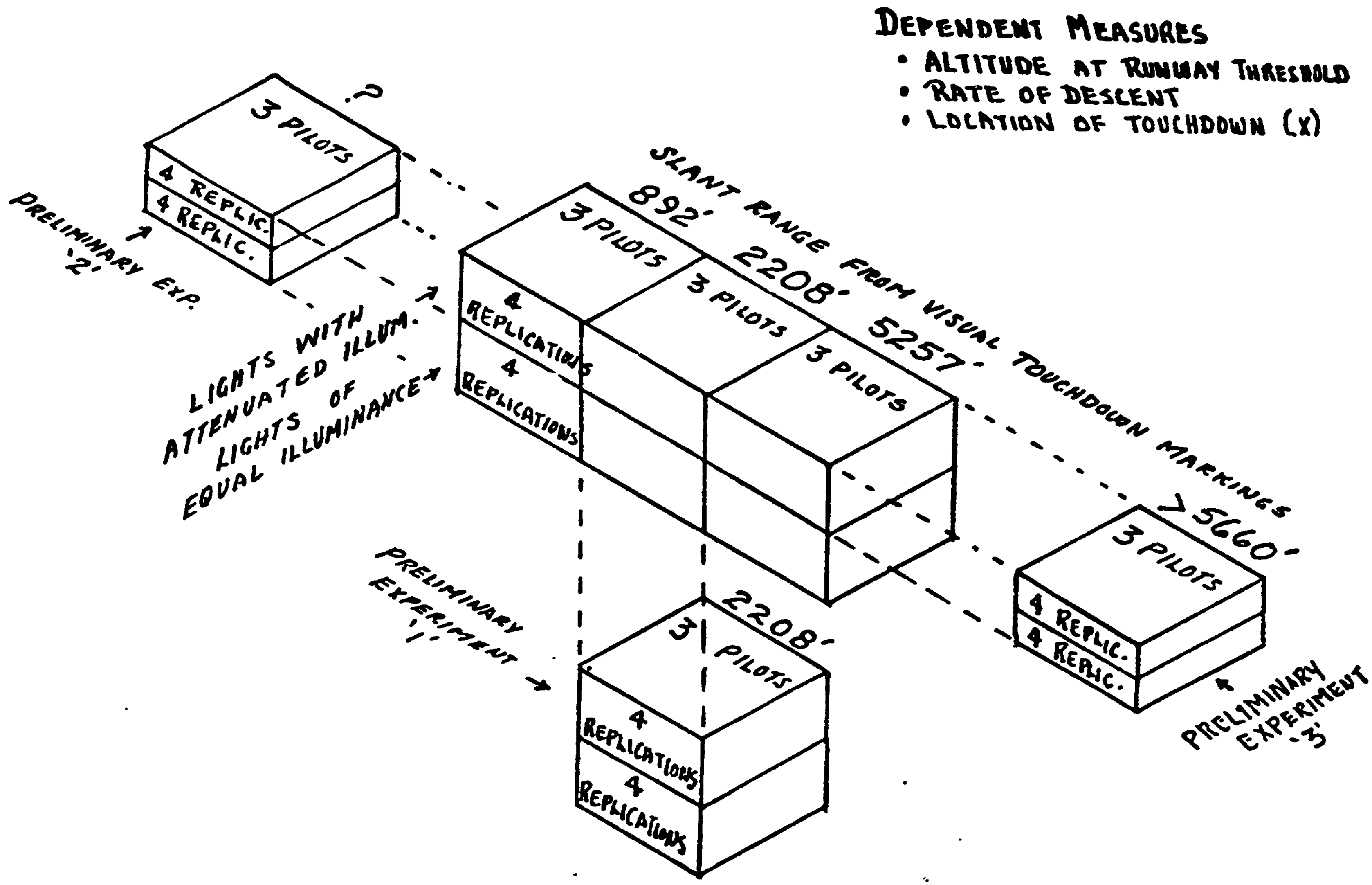

Figure 5 Experimental Design: Effect of Light Illuminance Distribution and Runway Texture Visibility on Approach and Landing Performance.

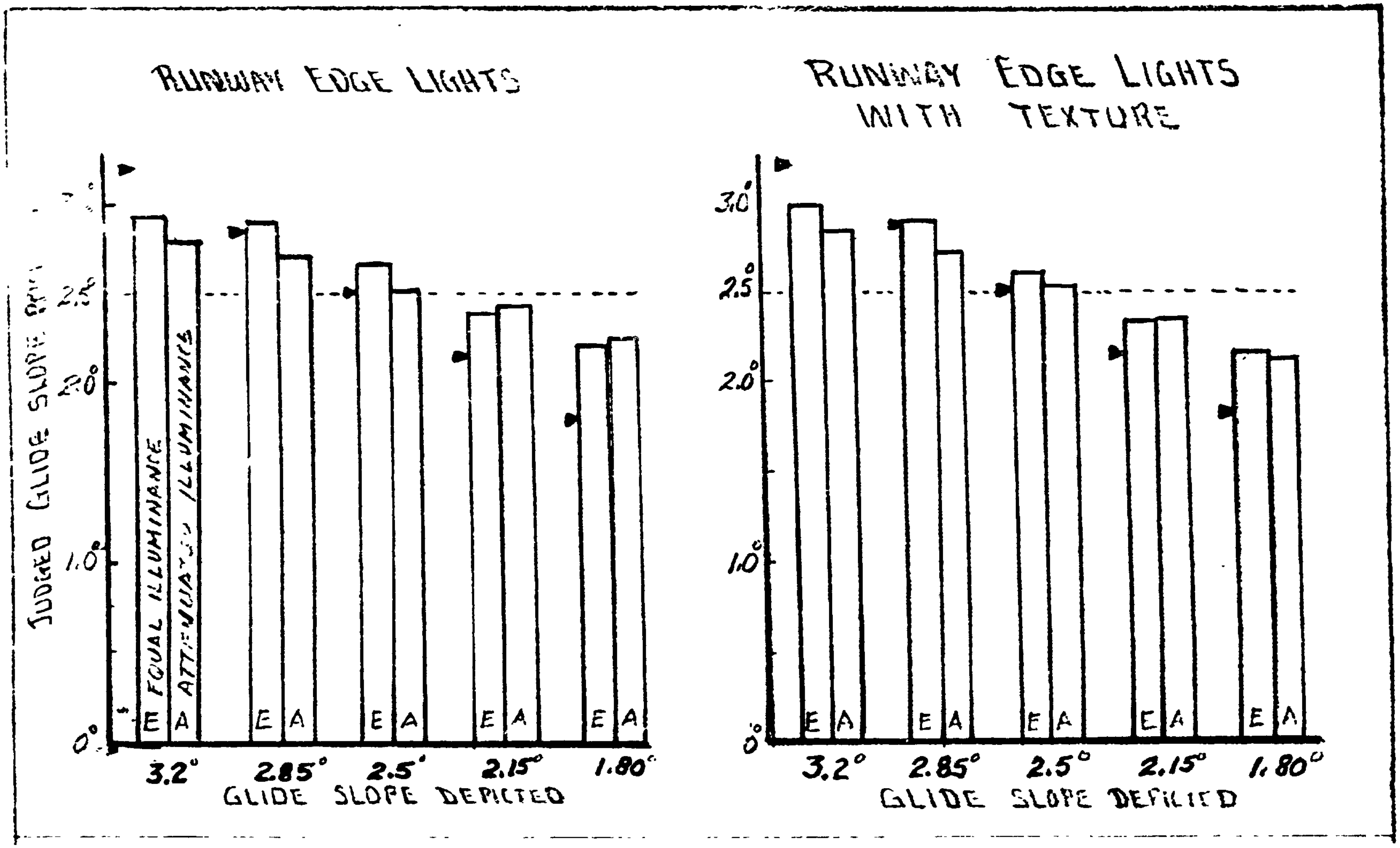

Figure 6 Pilots Judgement of Glide Slope Position from Static Photographs.

These averages should not be interpreted as illustrations of improved performance as the absolute value approximates the 2.5^{o} of the physical glide slope. If the pilots made no discrimination, the average would also be near 2.5^{o} as the scenes were balanced above and below this value. The regression of the estimates of the glide slope position as they are related to the illustrated glide slope position must be considered as shown below for the lights without runway texture.

Illustrated Altitude (glide slope in degrees)	Attenuated Luminance (glide slope in degrees)	Equal Luminance (glide slope in degrees)
1.80	2.44	2.51
2.15	2.48	2.58
2.50	2.52	2.64
2.85	2.56	2.71
3.20	2.60	2.77

Thus for each illustrated altitude the equal luminance scene gave the pilots the impression they were higher than for attenuated luminance.

The overestimation is found to increase in absolute magnitude, and similar to a constant glide slope angle difference, as a function of distance. Figure 7 illustrates this for the runway edge lights of equal luminance compared to a 2.5^{o} glide slope. Figure 8 also shows an underestimation of glide slope position when runway texture is visible but no runway edge lights are included in the scene.

<u>Dynamic Imagery</u>

Making a split half analysis of the data from the third preliminary experiment indicates that the technique is sensitive enough to show that the pilots will fly in a similar manner to lights and night scenes that are duplicates even with the instructive set that they are different. There was no statistical significant difference between the first and second half of the trials in this separate study.

A comparison of the absolute magnitudes and direction of the difference in altitude over the runway threshold between preliminary experiments two and three compared with number one were disturbing to the authors. The results indicated the possibility of a uncontrolled day-to-day variable. The cue to the variable of visibility of runway texture came from the static imagery study. We therefore controlled the visible range of the texture by freezing the simulator at specific distance on the glide slope and setting the texture to become just visible at this range.

There is a systematic interaction between the visibility of the runway texture and the light intensity conditions in the main experiment.

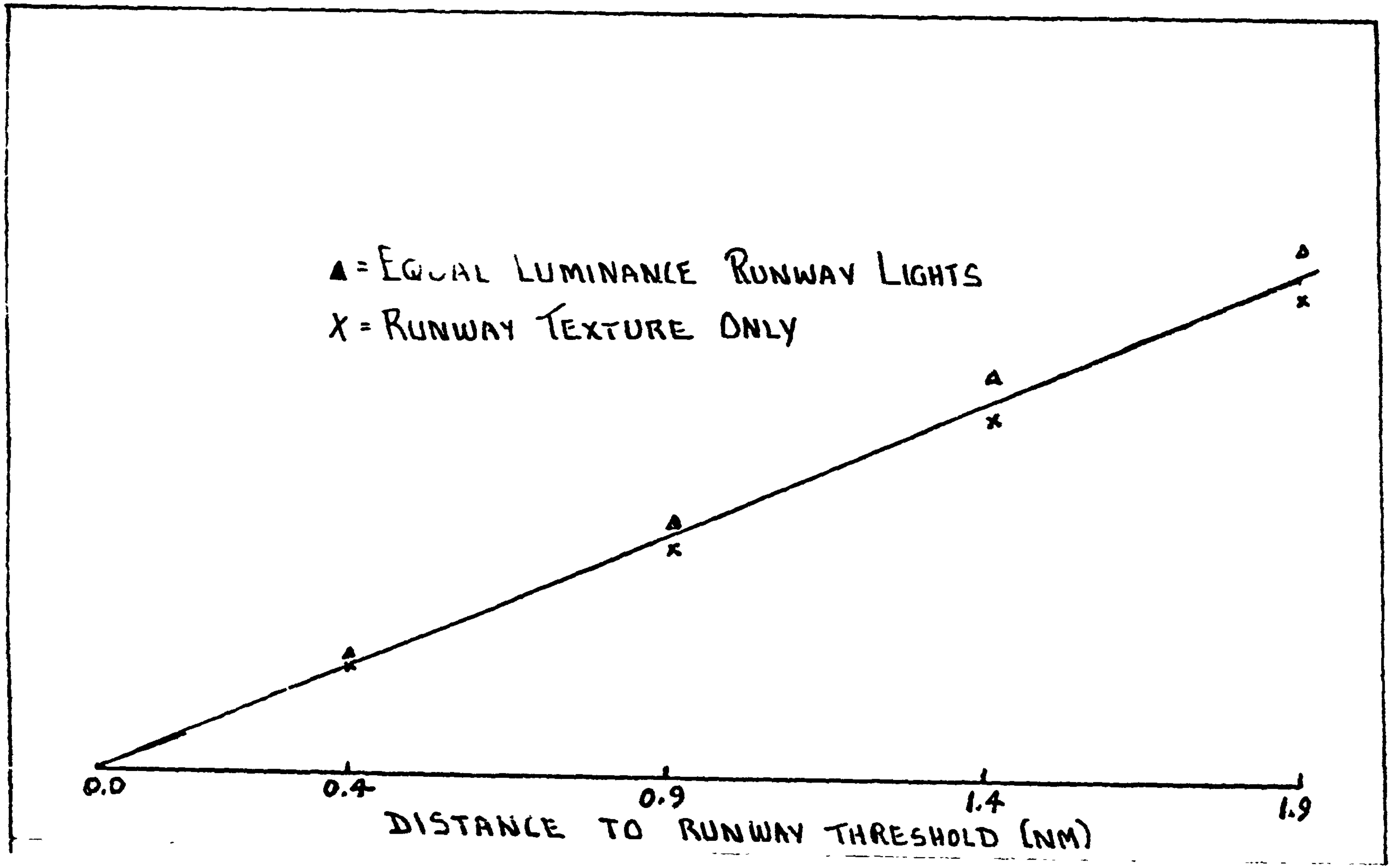

Figure 7 Effect of Runway Lights of Equal Luminance Compared with Texture Only on Glide Slope Estimations.

As runway texture becomes visible at greater slant ranges, the difference between the effect of attenuated light intensity vs. equal light intensity becomes less.

When runway texture is visible from 5275 ft. from the visual touchdown marks there are no differential effects due to luminance on the generated altitude at runway threshold (Figure 8). There is an 8.1 foot difference and a 14.5 foot difference when the visibility of the texture is delayed to 2208 and 892 feet respectively from the visual touchdown marks. These data do not represent statistically significant differences at any of the visibility conditions.

The lack of significance may be due to the small number of pilots used in the main experiment. Combining the preliminary experiment with its matching visibility conditions (2208') in the main experiment, allows us to combine the data from six different pilots, three very experienced and three recently qualified instructors. The difference in the means is 11.8 feet and this becomes statistically significant with an N of 24. In combining these data, approaches with the attenuated lights produce a mean runway threshold altitude of 51 feet, 7 feet above the 2.5^{0} visual glide slope (2.9^{0}), or a little above 1 dot high. The equal luminance lights condition resulted in a 39 foot height and a 2.2^{0} glide slope angle or 3/4 dot low. The combining of these data may give a better estimate of the effect of texture and light modulation at the middle range. The doubling of the range of visibility of the texture is associated with systematic change for each light condition (Figure 9).

The analysis of variance applied to the main experiment (3 pilots) indicated no significant differences among the main effects for three dependent measures: (1) Altitude over threshold, (2) descent rate at touchdown and (3) position of the touchdown along the runway. However, replication (first through fourth in each experimental cell) was significant for rate of descent. The respective means were 9.4, 7.6, 7.2 and 7.2 feet per second. These are averages over all conditions and indicate that improvement within each treatment condition continued until the third letdown.

A very significant interaction between light luminance distribution and replications was found for position of the touchdown. When pilots were approaching the scene that had the "attenuated with distance" lights, they progressively decreased their error from the first through fourth trials. The mean values were 286.4, 254.8, 59.5 and 35.2 feet beyond the front of the visual reference mark. Initially the landings were long and the progression was to decrease the distance to well within the length of the 1000 foot marker. However, when approaching the scene with equally luminous lights, the progressive change in touchdown position is away from the touchdown mark.

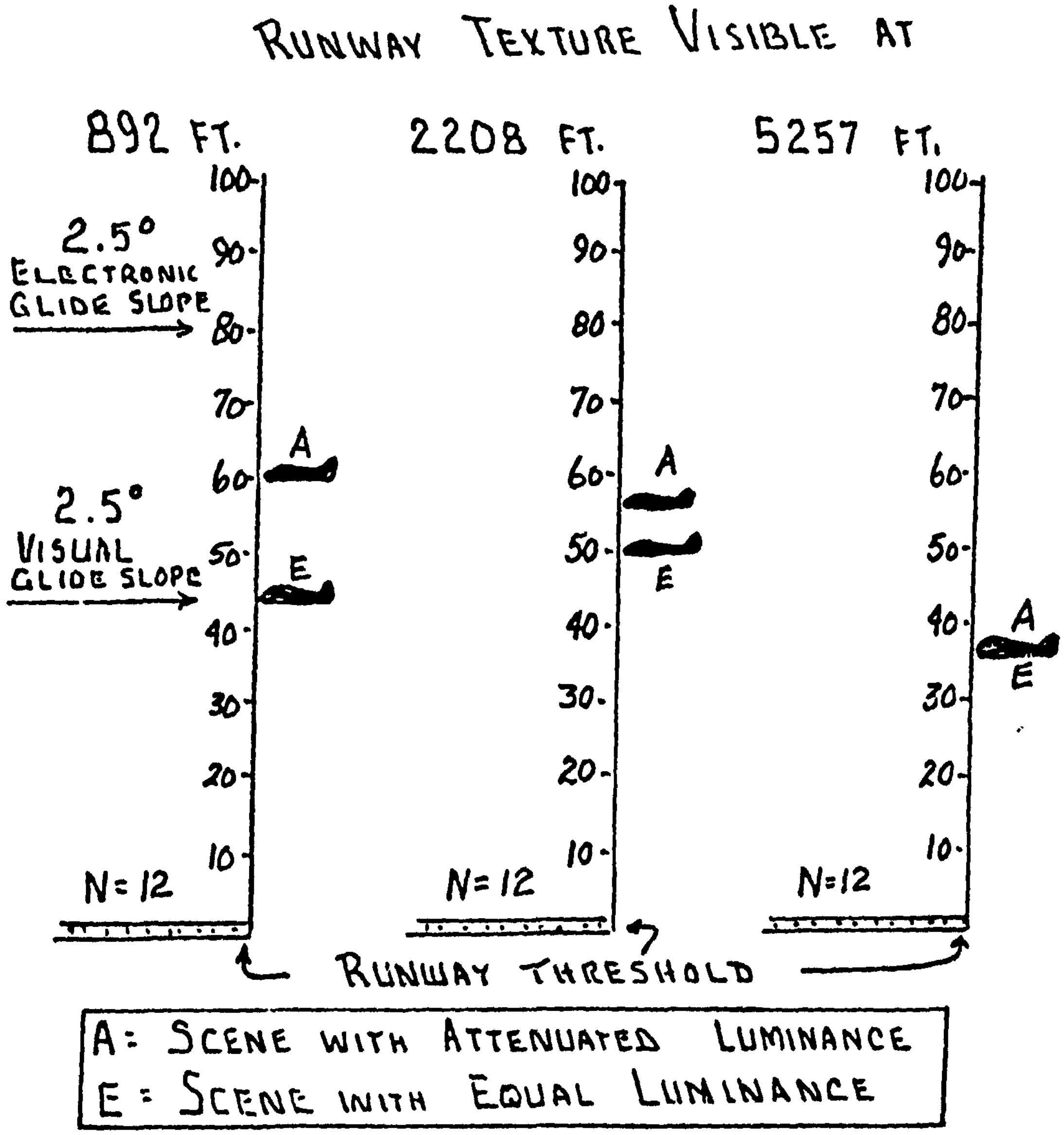

Figure 8 The Effect of Luminance and Runway Texture Visibility on Altitude at Runway Threshold.

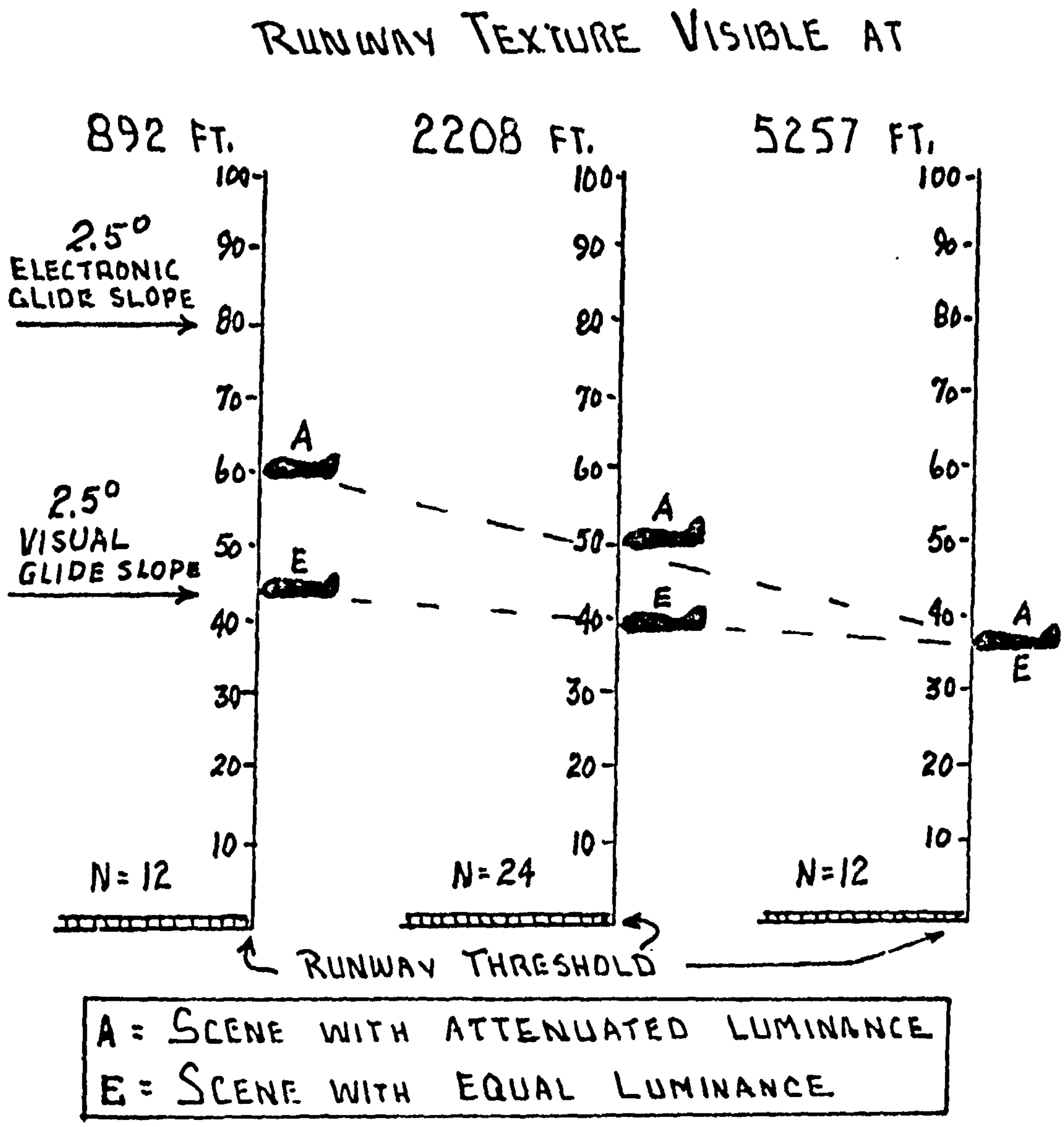

Figure 9 The Effect of Luminance and Runway Texture Visibility on Altitude at Runway Threshold.

The averages were; 44.6, 116.2, 219.8 and 200.9 feet. The main effect of replications for the touchdown distance variable was not statistically significant however (Figure 10).

DISCUSSION

The static and dynamic experimental results are compatible for the effect of luminance. In the static situation the depiction of MWH with lights of equal luminance were judged to have a higher aircraft position at each distance than the scenes with attenuated luminance. It follows then, that if pilots believe that they are higher than they really are, the flight paths that they generate tend to be lower. Lower flight paths to lights of equal brightness were measured in the main experiment. It is also noted that the overestimation of height is greatest when there is no runway texture in the static photographs. The earlier the runway texture becomes visible the lower the average flight path is when it is measured at the runway threshold, for both the attenuated and non-attenuated luminances. The higher flight path to the attenuated luminance exists until the texture of the runway surface is made visible from about one statute mile from the 1000' visual touchdown reference marks.

These results indicate that lights which have a change in luminance as a function of distance to compensate for too large a depicted light in CGI systems is an important variable when texture is not visible from a distance of 5000 or more feet. Systems which do not have this attenuation will train pilots to fly lower than they will in the real world situation and therefore the transfer of training should be less effective than it could be in CGI systems.

The static and dynamic experimental results differ as to the effect of runway texture on height estimation. The underestimation of the photographed altitude was not found to have a complement of an increased altitude in the dynamic part of this study. The results are however compatible with a yet to be published U.S.A.F. investigation wherein the same night scene has higher, at runway threshold altitudes, than the same day scene. In addition, pilots fly even higher when the night scene is viewed through poor quality windscreens while the day scene performance is not significantly changed. The explanation for both the U.S.A.F. and this study results may be that: (1) With less visual information displayed by the night Compuscene than the day scene, with its greater complexity, the pilots fly higher to the scene with the less information. (2) When poor optical quality windows add uncertainty to this lower amount of visual information pilots fly with greater caution and come in higher over the runway threshold.

The result which appears to have greatest import from this study is

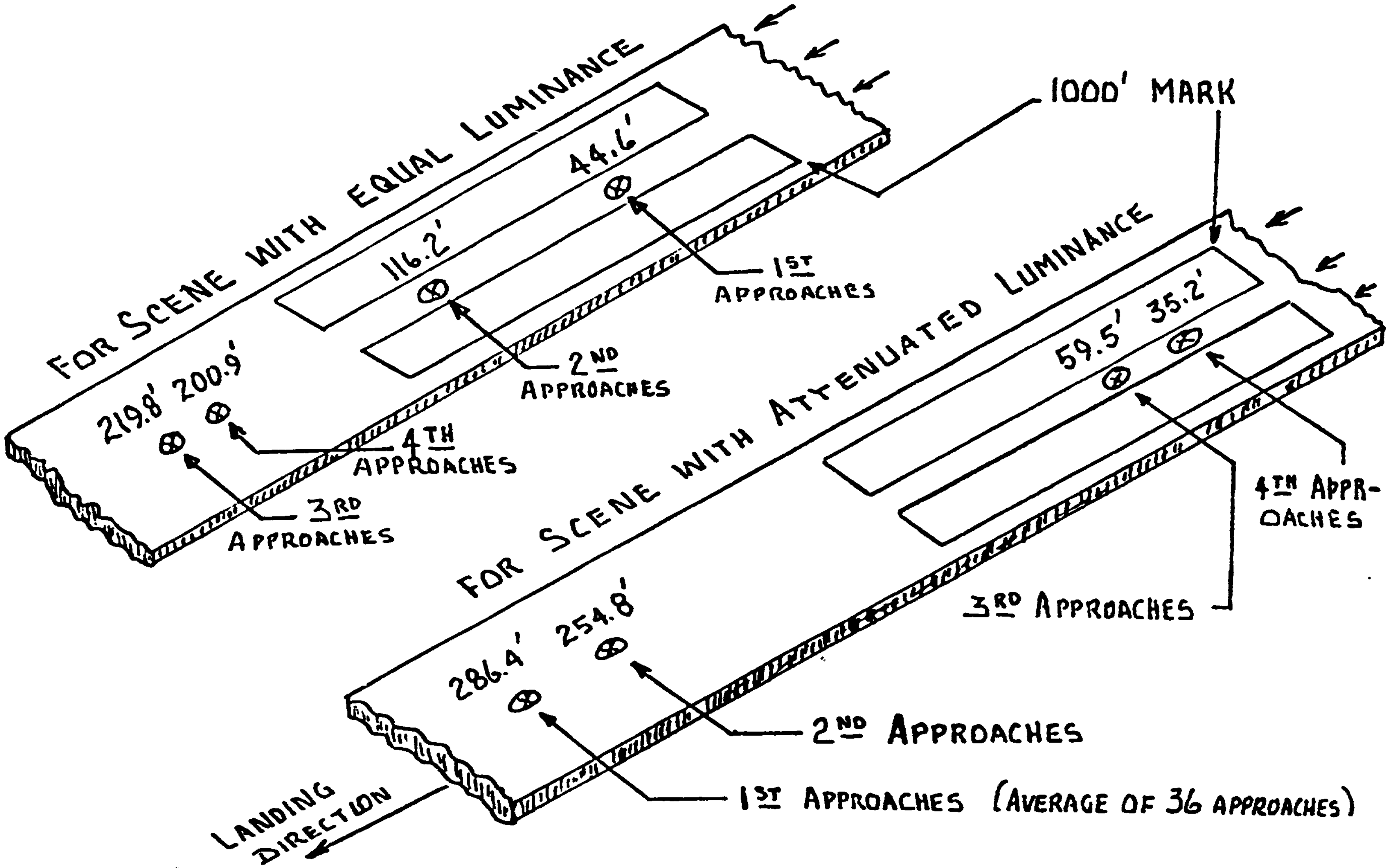

Figure 10 Touchdown Performance: Lights x Replication Interaction.

that the visibility of the runway texture must be set and controlled in day-to-day operations. It appears from these data that the best approximation to the glide slope will occur when the detail just becomes visible 2500 feet before the aircraft reaches the visual touchdown marks on the runway. Whether improved training may be obtained by matching night scene simulator performance with the glide slope, is not answered by this investigation. Training might best be served by practice with a variety of delays in the appearance of the texture, as this variable cannot be controlled in the real world. However the training community should be aware that this is an important variable which can be controlled for their purposes and benefit. In the General Electric system, this variable can be controlled by the day-to-day maintenance procedures with this method of setting the apparent contrast and texture brightness and its operation.

The rate of descent at touchdown is not altered by the luminance or texture variable improving only slightly with repeated trials within a session.

Touchdown position along the runway appears to improve with each replication or up to the fourth trial (the greatest number of trials in this study), with the attenuated luminances. These results suggest some learning within each session, where the results do not suggest this for scenes with equal luminance.

CONCLUSIONS

In computer generated images for flight crew training purposes the lights representing night scenes should have their luminance attenuated as a function of distance in a manner that also includes a correction for too large a depiction of distant point sources.

That all CGI systems should have a control as to where the runway texture becomes visible in night scenes. It remains for the research units of the training community to establish how best to use this variable in flight crew training. To approximate a 2.5^{o} glide slope the operational equivalent of 2500 feet as the visual threshold for runway texture may be used as an initial reference point for such research.

Reference

Kraft, C. L., Anderson, C. D., and Elworth, C. L., Windshield Quality and Pilot Performance AMRL-TR-77 - Yet to be published study supported by U.S.A.F. Contract Number F-33615-76-0516.

SESSION II

Chairman
Richard S. Dunn, Ph.D.
Engineering Psychologist
U.S. Army Air Mobility Research & Development Laboratory
Ames Research Center
Moffett Field, California 94035

Richard S. Dunn, Ph.D.

Dr. Dunn participates in the Laboratory management process as the technical specialist for Human Engineering research in the Air Mobility Laboratory. Current programs include the development of an advanced helicopter flight simulator for research and development and the development of new methods for measurement of aircrew workload. Previous experience includes employment at the US Naval Air Test Center, Patuxent River, MD., in the field of flight test evaluation; and at the US Air Force Flight Test Center, Edwards AFB, California in a similar capacity. He studied experimental psychology at the University of Florida (Ph.D.) and is also a graduate of Western Michigan University (MA) and Rensselaer Polytechnic Institute (BS).

AN OPAQUE TARGET OPTICAL PROJECTION SYSTEM (OTOPS)

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Lead Design Engineer
Vought Corporation
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PAST EXPERIENCE: U.S. Government White Sands Missile Range, both as a co-op student and engineer involved in photo-optical instrumentation of guided missile flight.

Vought Corporation (formerly LTV Range Systems Division) of NASA White Sands Test Facility as supervisor of the Optical Calibration Laboratory.

Link Group (Singer) at NASA Houston as visual systems engineer on the Apollo Command Module Simulators used for astronaut training.

EDUCATION: B.S. Mechanical Engineering, New Mexico State University,1964.

AN OPAQUE TARGET OPTICAL PROJECTION SYSTEM (OTOPS)

Joe L. Walker
Vought Corporation

The resolution and realism of the target aircraft image in an air combat simulator visual display is by far the most critical part of the total visual scene. Without display resolution that matches the pilot's visual acuity the pilot cannot determine the aspect or attitude changes of the target aircraft and therefore cannot respond in a realistic manner to his opponent's maneuvering.

For the last 2 years Vought Corporation has been leasing its engineering air combat simulator facility to the Air Force Tactical Air Command for F-4 pilot training. This training experience confirmed the validity of the above statement and has shown that the major simulator hardware deficiency was the target aircraft image resolution. To correct this deficiency the Opaque Target Optical Projection System (OTOPS) was developed.

At this point a slight digression to describe the Vought Air Combat Simulator Visual Display as it existed prior to OTOPS is in order to better understand how and why OTOPS was implemented.

The simulator visual display (Figure 1) is conceptually similar to the NASA Differential Maneuvering Simulator where imagery from a gimballed sky/earth projector and a target projector are displayed on a spherical screen surrounding the pilot. The target projector utilized a high brightness CRT, fixed projection optics and a gimballed steering mirror to project and position the target image within the pilot's view.

The image generation technique used for the target projector was computer image generation which constructed images (Figure 2) which were stick-figure in nature. The image size was varied on the projection CRT face to simulate the target range. The major deficiencies of this system were:

- The lack of realism in the stick figure images made attitude determination difficult.
- The limited dynamic range of image sizes possible due to spot size limitations severely degraded the image resolution at the longer ranges.

OTOPS was developed to provide an improved target image The basic concept employed is the same as the typical opaque projector common to

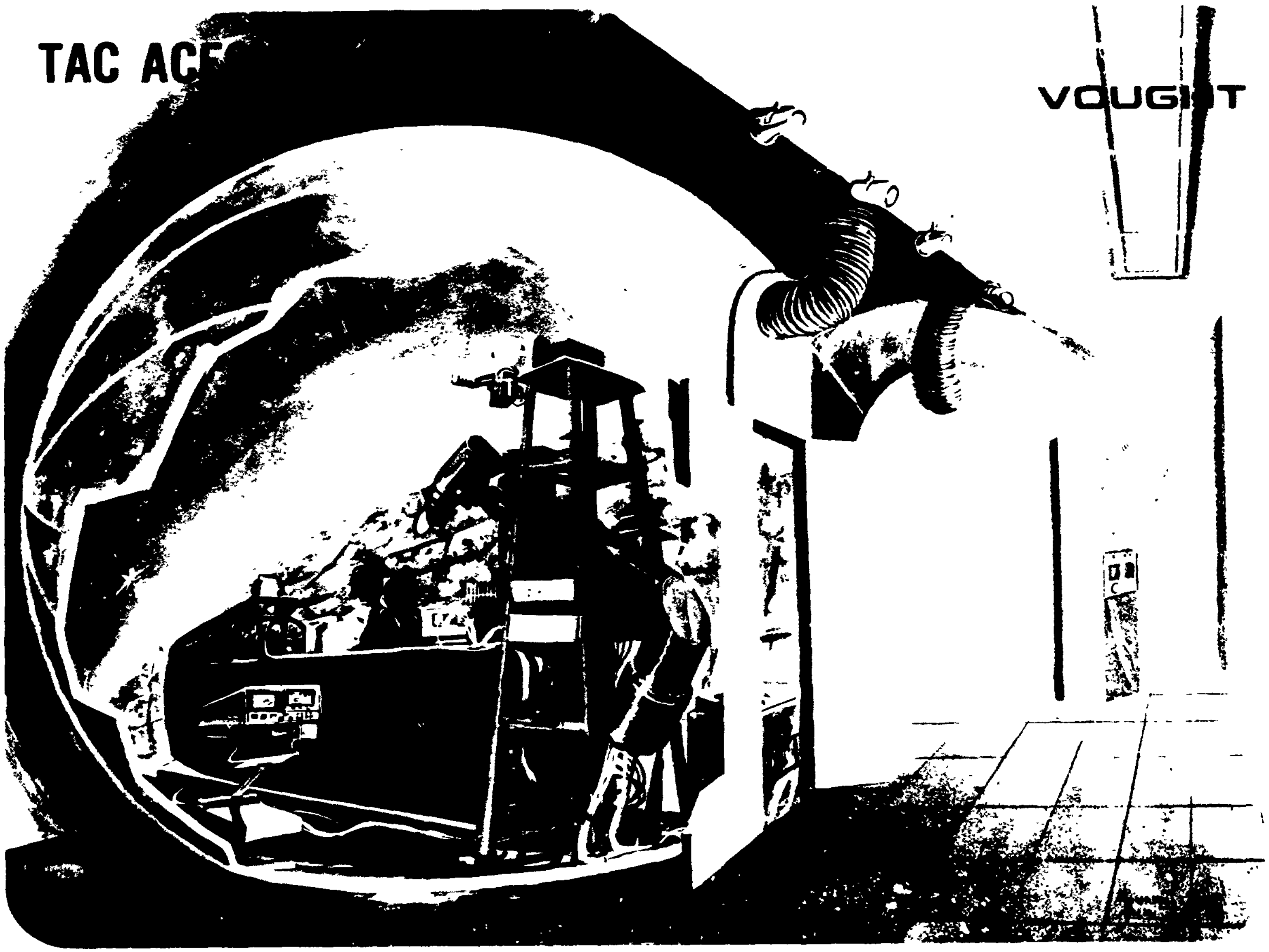


Figure 1

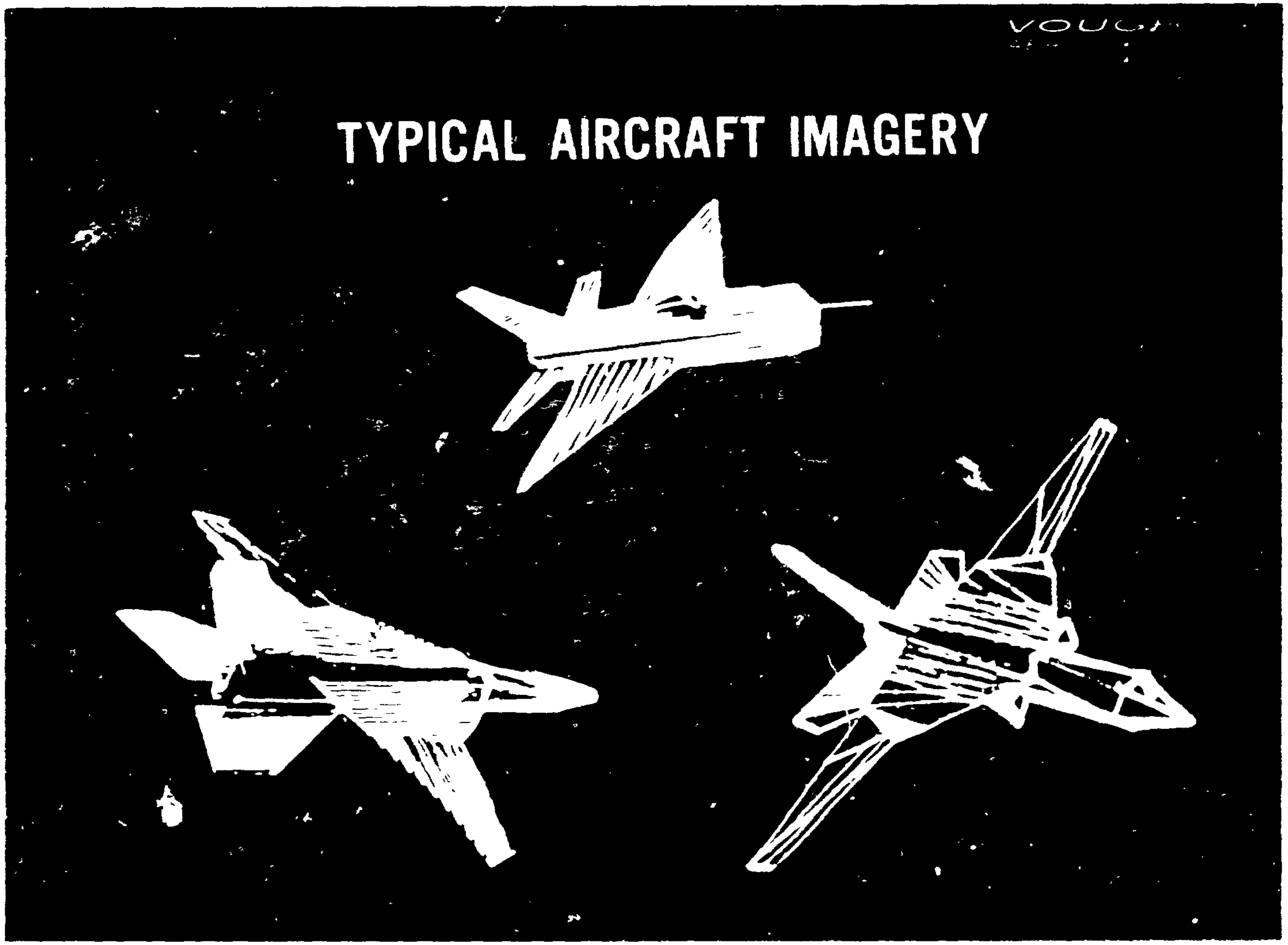


Figure 2

the educational audio visual field where opaque material is projected directly without the necessity of slides or transparencies.

The total overall projector concept as applied to the Vought Air Combat Simulator is depicted in Figure 3 and described as follows. As shown, a gimballed aircraft model (1) is intensely illuminated by illuminators (2) and then projected directly via zoom projection optics (3), a fixed mirror, or corner reflector (4) and a gimballed mirror (5) and displayed to the pilot on a spherical display screen (6) as a real image (7). The corner reflector and gimballed mirror are the ones originally used in the Air Combat Simulator Target Projector.

The various elements of the complete target projector serve the following functions:

- The model gimbal system rotates the model so that the correct aspect is viewed by the simulator pilot.
- The coupled zoom lenses serve to project the target image and change the image size over a 40:1 dynamic range to simulate range to the target.
- The corner reflector and the gimballed mirror serve to direct the projector optical axis so that the target image is displayed on the spherical screen to simulate the correct azimuth and elevation angles to the target from the simulator pilot.

Figure 4 shows in greater detail the configuration of the OTOPS projector gimbal system. The system contains two identical orthogonal 3 axis gimbal systems, one positioning a nose sting supported model and the second positioning a tail sting supported model. Either of these gimbal systems can be selected by a pneumatic powered quick dissolve mirror assembly which is computer controlled to select the model that is not occulted by the gimbal structure. The quick dissolve mirror serves an additional function in that it also directs the light from 4 xenon lamps to the selected model.

The system optical axis as shown by the heavy black line in Figure 4 passes through an image rotator (K-Ray Mirror Assembly) which provides a redundant axis that is programmed to avoid the classic gimbal lock problems. The optical axis then proceeds to the zoom optics package which serves to scale the projected image size as a function of aircraft separation.

The zoom optics consist of a 10:1 zoom lens and a 4:1 zoom lens coupled to provide a total 40:1 optical zoom range. The lenses are off-the-shelf optics and are mechanically mounted with both zoom rings driven simultaneously by the same computer controlled servo system. The

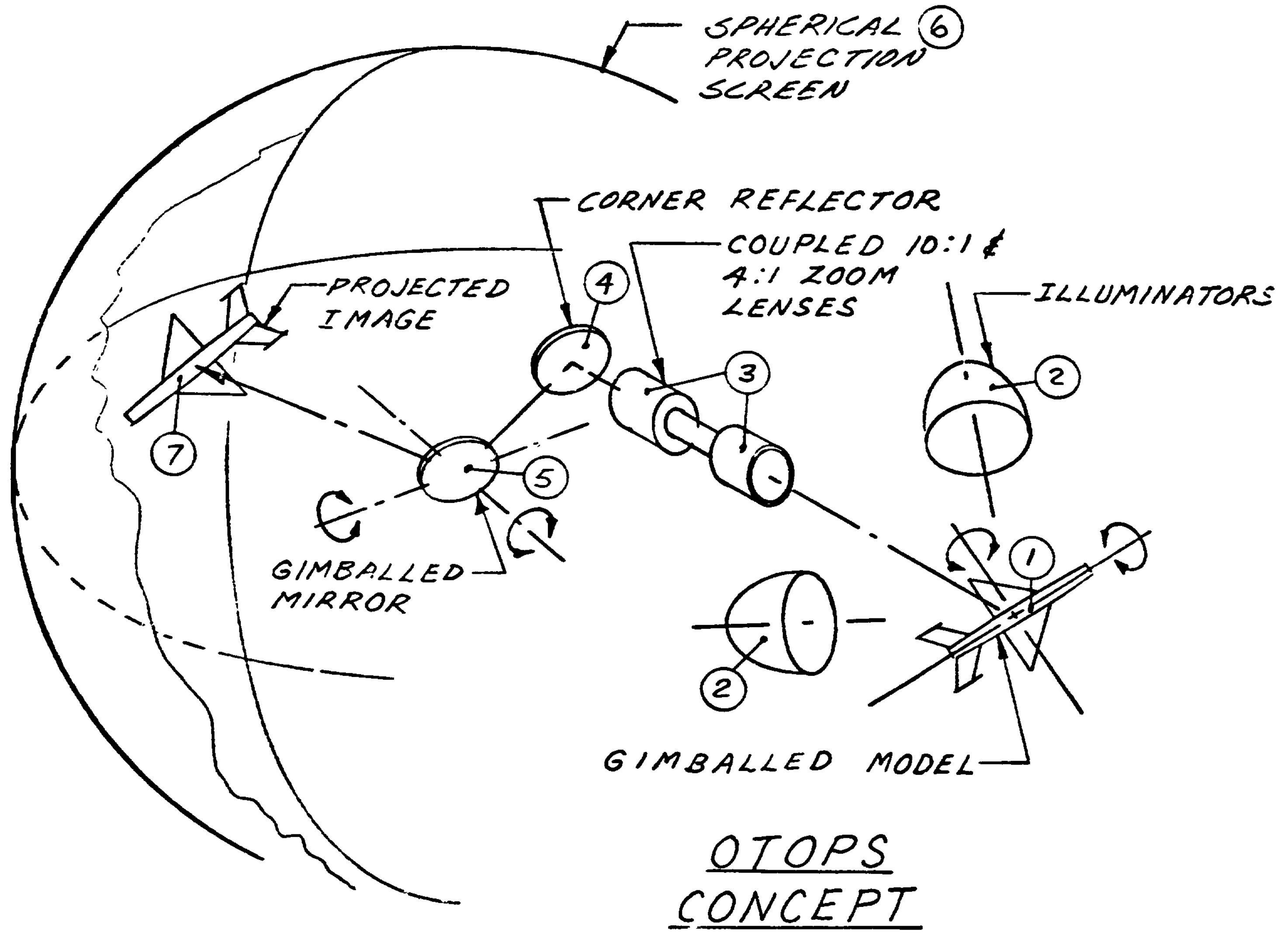
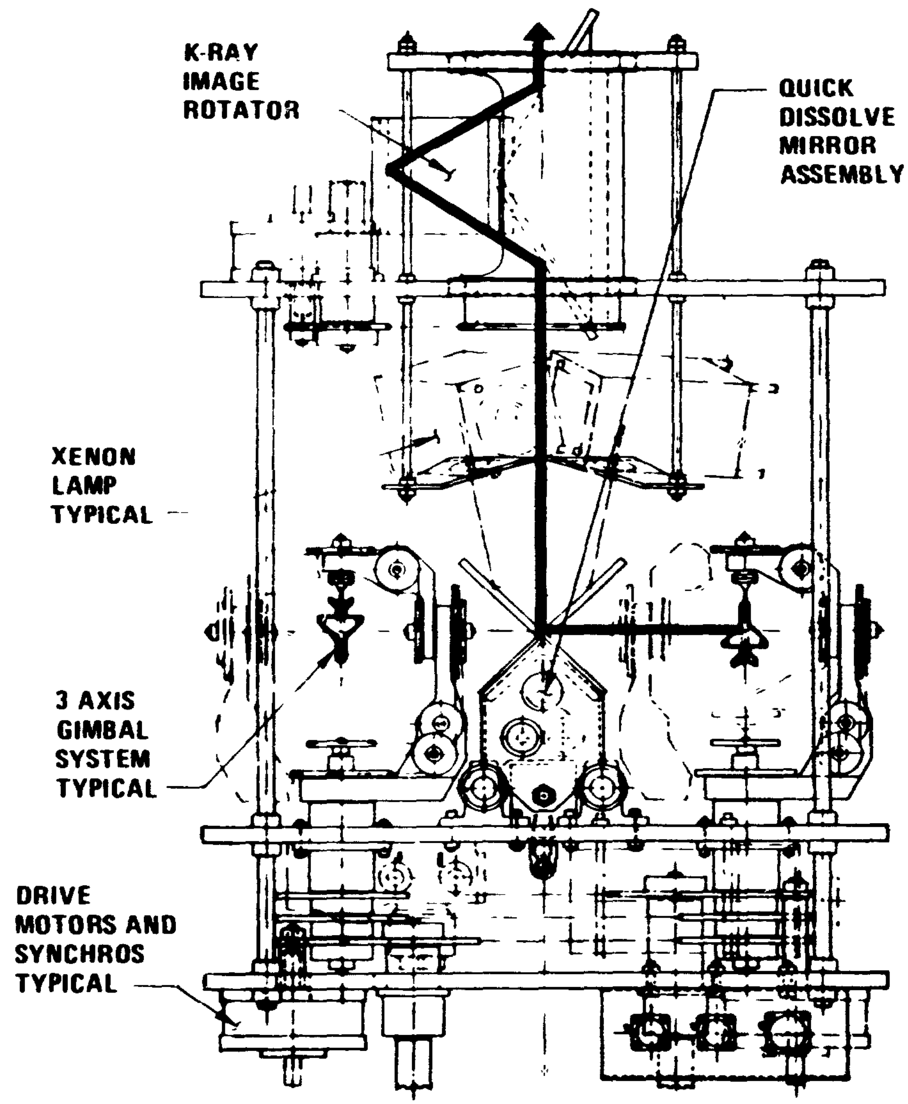

SPHERICAL 6 PROJECTION SCREEN
CORNER REFLECTOR
COUPLED 10:1 & 4:1 ZOOM LENSES
ILLUMINATORS
PROJECTED IMAGE
4
3
2
7
5
1
GIMBALLED MIRROR
2
GIMBALLED MODEL
OTOPS CONCEPT

Figure 3

OTOPS
PROJECTOR
GIMBAL SYSTEM



VOUGHT

P6 1097 1

Figure 4

iris of one lens is also servo controlled as a means to control the brightness of the displayed image. The projected beam is then directed by the original visual system gimballed mirror to correctly position the image on the display screen.

To reduce the component cost of OTOPS a means to drive both of the orthogonal 3 axis gimbal systems with common servo components was devised. Figure 5 shows the mechanical arrangement of the 3 axis gimbal systems. As shown all three axes are driven by drive inputs all concentric with the outer axis and the desired transmission of torque to each axis is achieved by gears and toothed drive belts. Each axis of the 3 axis gimbals are also mechanically coupled together by toothed drive belts driven by a common servo motor/techometer and position transducer.

This gimbal arrangement has some definite advantages.

- Each axis of both gimbals styas in synchronization.
- Servo component cost is reduced.
  - Common servo components, 4 identical servo systems.
  - Requirements for slip rings deleted.
  - Servo components themselves do not add to axis inertias. Less efficient and lower cost components can be used.

The three mechanical rotational axes and the image rotator provide a 4 axis gimbal system that

- Prevents occulting of the model by its gimbal support structure. Using two gimbals either of which can be selected by the quick dissolve mirror assembly assures that the gimbal support structure does not block the model visibility.
- The redundant image rotator and the orientation of the other gimbal axis provide a gimbal lock free configuration with reasonable peak velocities for any axis.
- Positive slip free coupling of the model to the servo position transducers of all axes, providing drift free operation.

Figure 6 shows how the OTOPS hardware was added to the original visual system hardware so that minimal modification was required. As shown, the zoom optics package was installed in place of the original fixed optics and the model gimbal assembly was added to the rear of the original projector.

OPAQUE TARGET OPTICAL PROJECTION SYSTEM

3 AXIS GIMBAL SYSTEM

VOUGHT

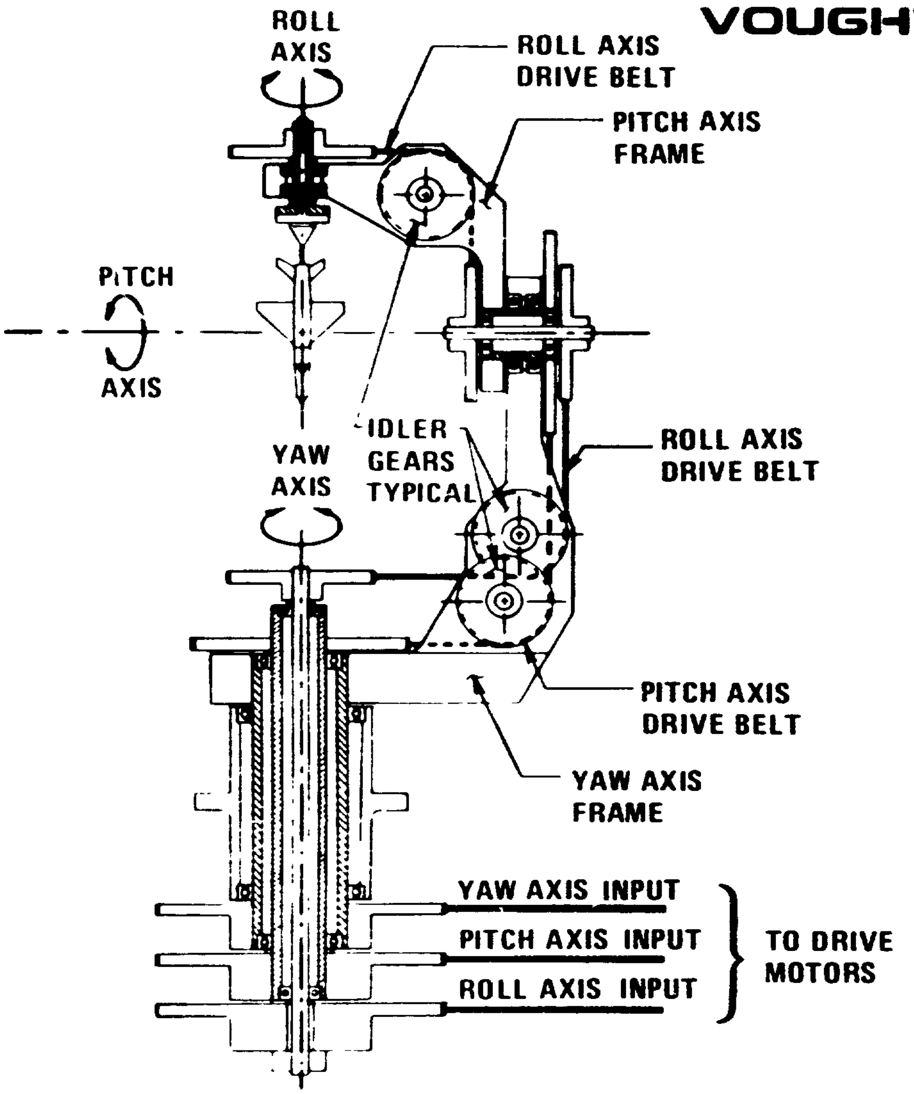


Figure 5

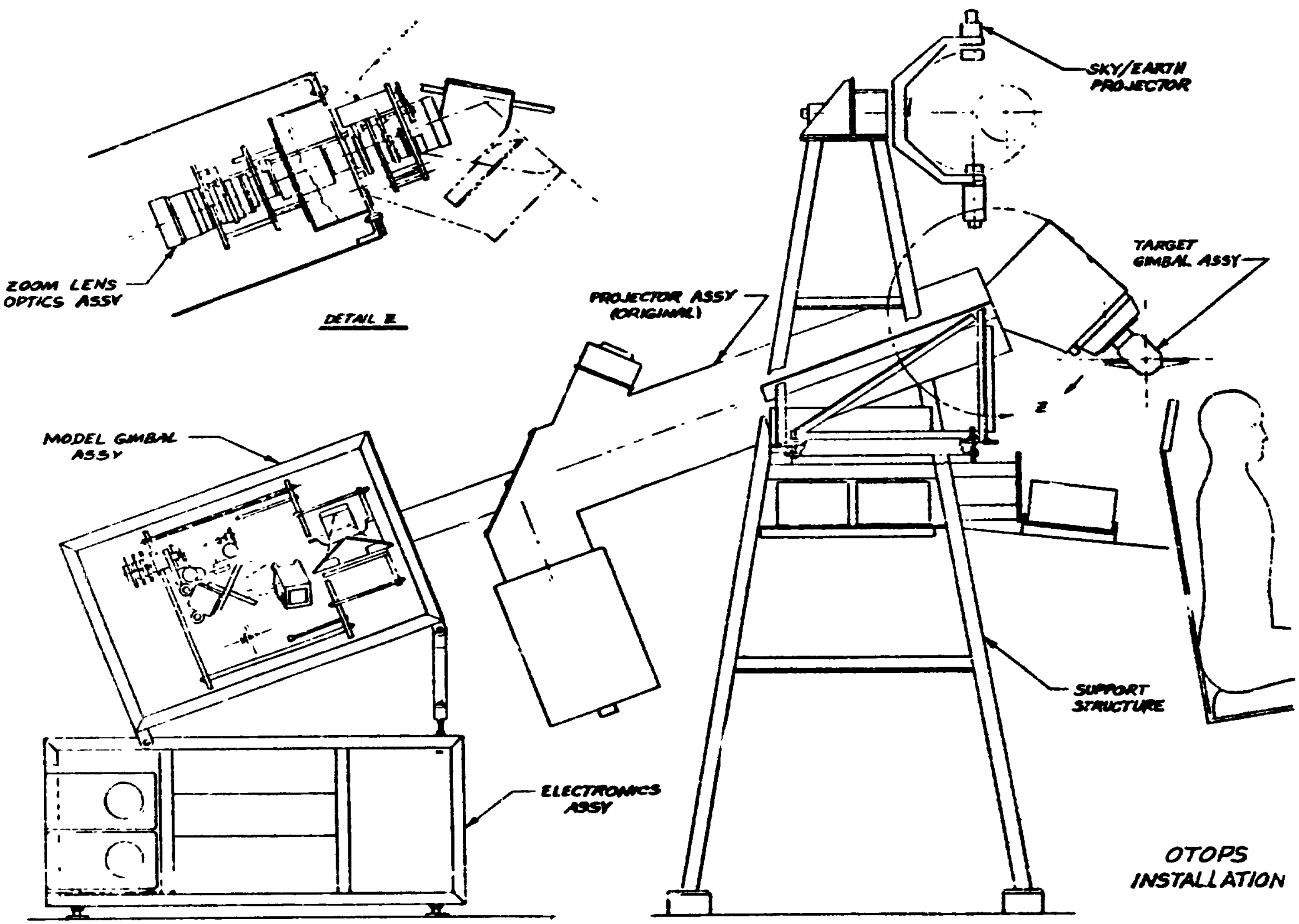

SKY/EARTH PROJECTOR
TARGET GIMBAL ASSY
ZOOM LENS OPTICS ASSY
DETAIL Z
PROJECTOR ASSY (ORIGINAL)
MODEL GIMBAL ASSY
SUPPORT STRUCTURE
ELECTRONICS ASSY
OTOPS INSTALLATION

Figure 6

The advantages of the OTOPS concept over present target projectors used in visual display systems for Air Combat Simulators are as follows:

All presently operating systems use closed circuit TV systems consisting of a TV camera viewing a gimballed model with the displayed image projected by a TV projector. OTOPS by utilizing direct optical projection avoids the usual problems associated with TV projection.

- OTOPS provides better resolution since the overall system transfer function is not limited by the transfer function of typical TV components.

- Projection of color is free. If the model is decorated in various new colors associated with insignia or camouflage of the target, these are realistically displayed in the projected image. A target projector system utilizing the TV approach would require very expensive color cameras and projectors.

- OTOPS utilizes inexpensive off-the-shelf zoom lenses greatly reducing the system cost. In TV projector systems special design zoom projection lenses are required to match the large format sizes of the projection cathode ray tubes used in these systems.

- By not using the TV components, OTOPS reduces the price of the typical target projector by $60,000 to $80,000 depending on the system design.

AREA OF INTEREST SIMULATION WITH VARIABLE SIZE
HOOD TO RESTRICT VIEWABLE SCENE

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Mr. Kelly has a B.S. and M.S. Degree in Math and has made significant contributions in the design of the algorithms used in the Hardware and Software of the ASPT CIG Visual System. Mr. Kelly has worked for the past 12 years in Simulation System design and development.

Mr. Kelly is currently working as a CIG Visual Simulation System Engineer at Williams AFB, Arizona.

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Software Systems Analyst
Space Division
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Mr. Turnage has a degree in Computer Technology and has fourteen years experience with computers and software systems with three years experience being in visual simulation system software design/development.

Mr. Turnage is currently working as a Software System Analyst at Williams AFB, Arizona.

AREA OF INTEREST SIMULATION WITH VARIABLE SIZE HOOD TO RESTRICT VIEWABLE SCENE

WILLIAM A. KELLY and GEORGE R. TURNAGE

I INTRODUCTION

The purpose of this document is to describe the operational characteristics and the functional steps of implementation of the ASPT capability called the Area-of-Interest (AOI)/ Variable Field-of-View function.

The AOI function directs the ASPT Special Purpose Computer to output (display) the full system edge capacity (2560 edges) within the field-of-view specified by the user thus permitting a much more dense (detailed) scene than is possible without the AOI function.

The Variable Field-of-View portion of the AOI function allows the user to define the sized field-of-view desired and constructs a "hood" to mask out all scenery outside the area defined by the selected field-of-view. All display channels and segment of channels outside the field-of-view are displayed as a dark gray shade representing the "hood".

The primary function of the Advanced Simulator For Pilot Training (ASPT) system is in the research area. ASPT is probably the largest operational visual system in the field today and with its large field-of-view and high edge capacity it makes an ideal system to evaluate effects of field-of-view size on pilot performance. Another research area to be evaluated is how much more detail in the visual presentation is required for acceptable pilot performance.

II DEFINITION OF TASKS

The necessity to investigate these areas resulted in a set of requirements to General Electric to modify the ASPT system to provide the following:

A) Generation of a visual mask or hood which would restrict the visual scene to selected vertical and horizontal fields-of-view.

B) An operator interface which would allow the user to select any size field-of-view with minimum set-up time.

C) The capability to orient the hood along the line-of-sight as supplied by a pilot's head orientation sensor, in real-time.

D) Concentration of the total system edge capacity within the selected field-of-view. This included interfacing with the on-line adjustment of the hood orientation as defined by the pilot's head motion.

E) Generation of the horizon image such that it was visible through the hood, but no other edges would be visible.

F) An option to allow the orientation of the hood along the line-of-sight to track the horizon.

The approach to the solution to each of the above tasks will be outlined below. Figures and pictures will verify the approach and a movie demonstrating the visual effect will be shown.

III Task A - The more obvious means to create a hood were found to be not flexible enough for this application. For example, a cardboard overlay on the view windows would be very restrictive. For every possible field-of-view, a new overlay would be required. The choice then narrowed down to a model in the data base positioned at the eyepoint such that the objects of the model obscure everything but those within the field-of-view, (see Figure I).

From Figure II, there are four objects shown in an exploded view of a sample hood. With the viewpoint located at the origin of the hood model, the field-of-view is then determined by the location of the vertices (points in space) defining the front edges of each object. The vertices labeled V_A and V_B are fixed, so a particular field-of-view utilizing this hood would require computing only four vertices.

In order to provide the necessary flexibility, the four vertices are expressed in terms of field-of-view angles as defined below:

AZ_L ~ left azimuth angle

AZ_R ~ right azimuth angle

EL_T ~ top elevation angle

EL_B ~ bottom elevation angle

These angles are shown in Figure III with the front vertices labeled. These vertices can be defined as follows:

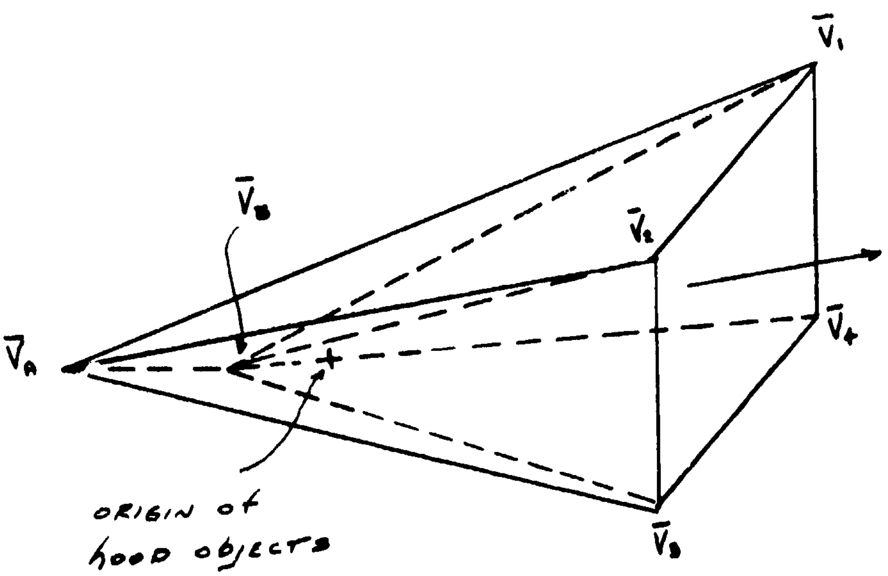


Figure I

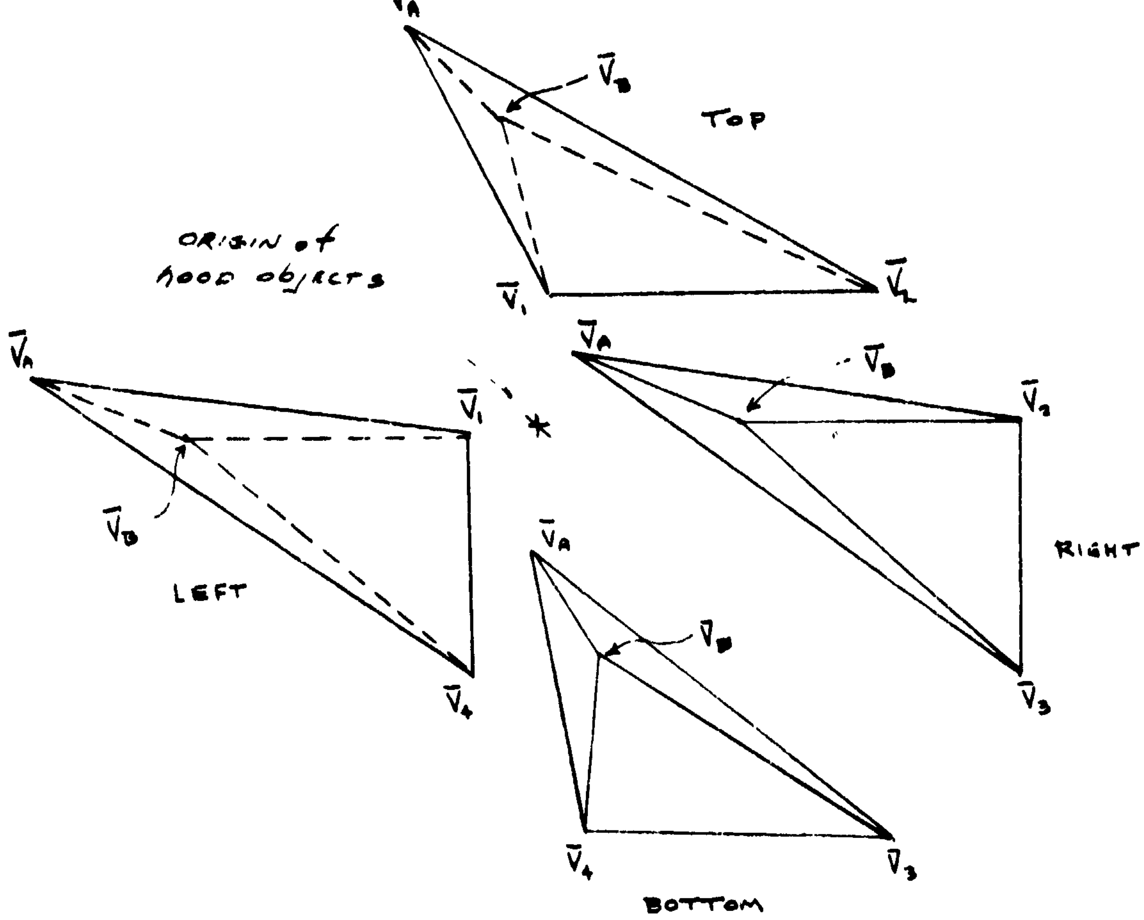
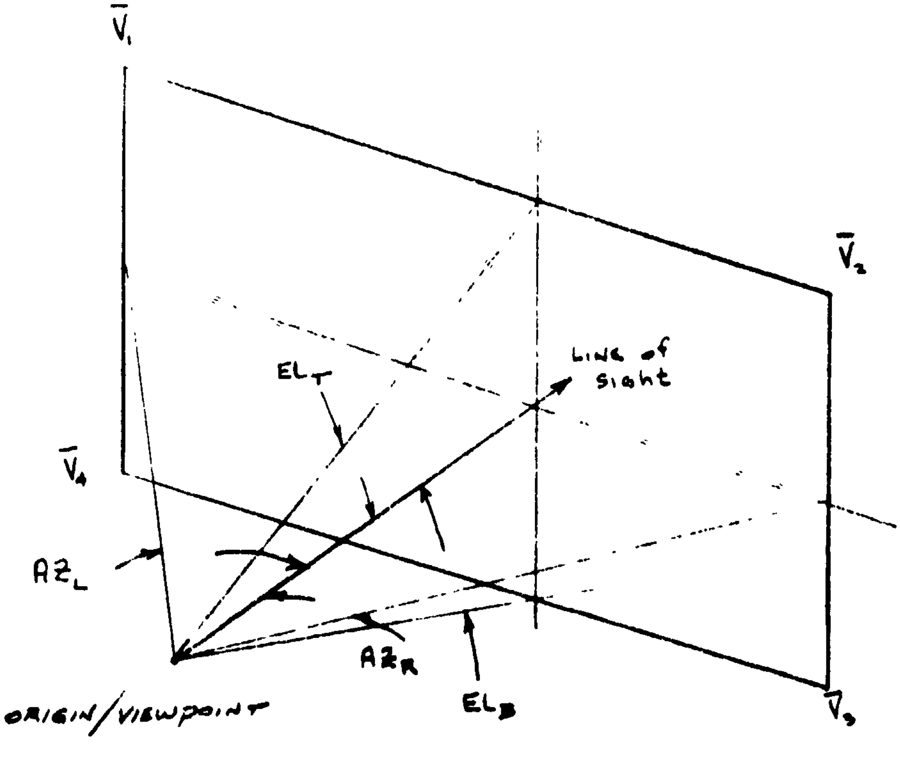


Figure II



$\bar{V}_1$
$\bar{V}_2$
$\bar{V}_3$
$\bar{V}_4$
Line of sight
EL_T
EL_B
AZ_L
AZ_R
ORIGIN/VIEWPOINT

Figure III

For vertices $\overline{V}_i$

$$X_i = \cos AZ_i \cos EL_i \qquad (1)$$

$$Y_i = \sin AZ_i \cos EL_i \qquad (2)$$

$$Z_i = -\sin EL_i \qquad (3)$$

These co-ordinates are relative to a co-ordinate system origined at the viewpoint with the axis defined as follows:

Positive X ~ out the nose of the aircraft.

Positive Y ~ out the right wing of the aircraft.

Positive Z ~ down

For narrow field-of-view requirements this hood serves as a useful tool. But the requirement for ASPT was to evaluate any field-of-view up to the full field-of-view of the display system. Consider a configuration as shown in Figure IV A with a wide azimuth definition.

The angle labeled (θ) is the true elevation measured along the line-of-sight. Setting up an equal distribution of azimuth left and right yields the true elevation angle as

$$\theta = \tan^{-1} \frac{(\tan El)}{\cos AZ} \qquad (4)$$

For wide angle requirements this would yield a projected hood as shown in Figure IV B. This resulted in defining a hood as shown in Figure V which for the required angular inputs would yield an error in elevation angle less than 5% of the required input.

Four angles are used to describe the total field-of-view and the vertices outlining the field-of-view are:

$$V_1 = \cos (AZ_L) \cos (EL_T), \sin (AZ_L) \cos (EL_T), -\sin (EL_T) \qquad (5)$$

$$V_7 = \cos (AZ_R) \cos (EL_T), \sin (AZ_R) \cos (EL_T), -\sin (EL_T) \qquad (6)$$

$$V_8 = \cos (AZ_R) \cos (EL_B), \sin (AZ_R) \cos (EL_B), -\sin (EL_B) \qquad (7)$$

$$V_{14} = \cos (AZ_L) \cos (EL_B), \sin (AZ_L) \cos (EL_B), -\sin (EL_B) \qquad (8)$$

A photograph of the hood as seen from outside the enclosure is shown in Figure VI.

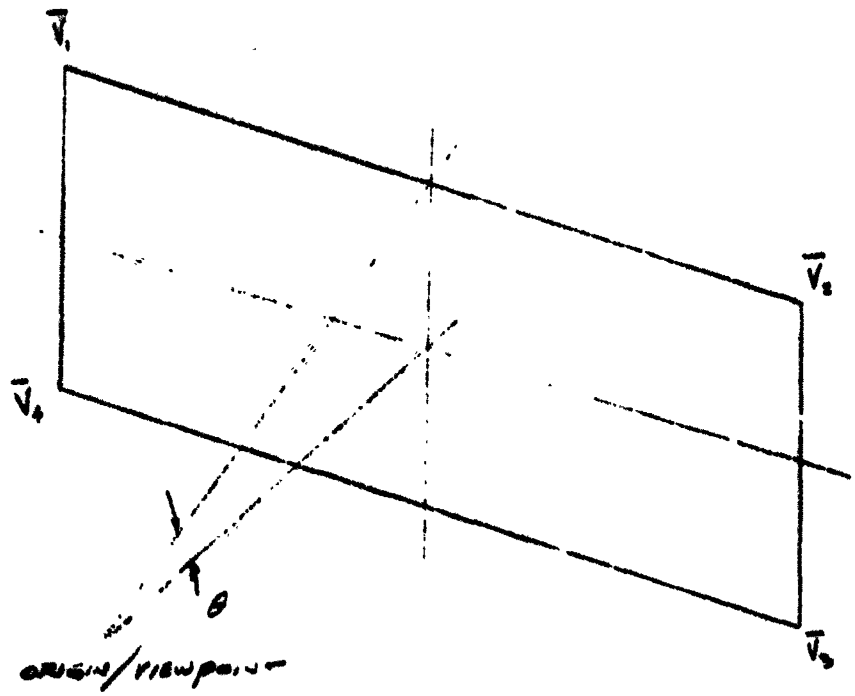


Figure IV A

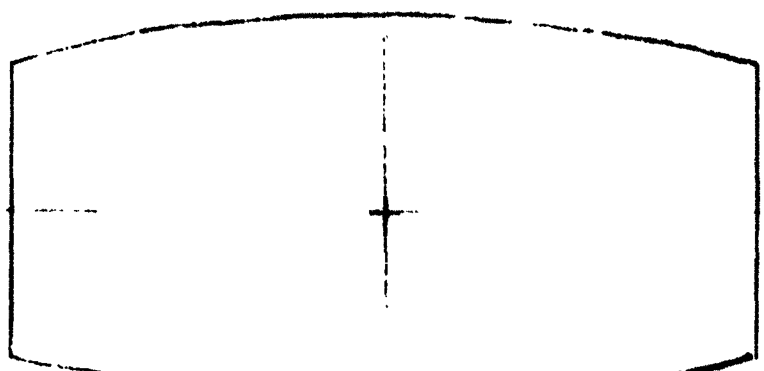


Figure IV B

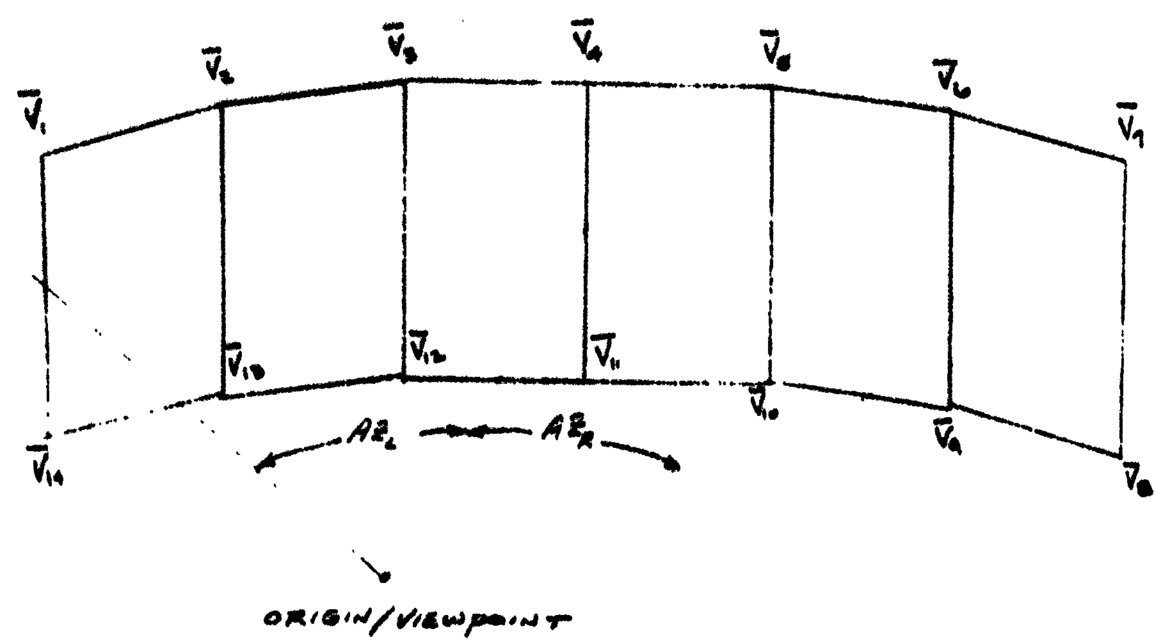


Figure V

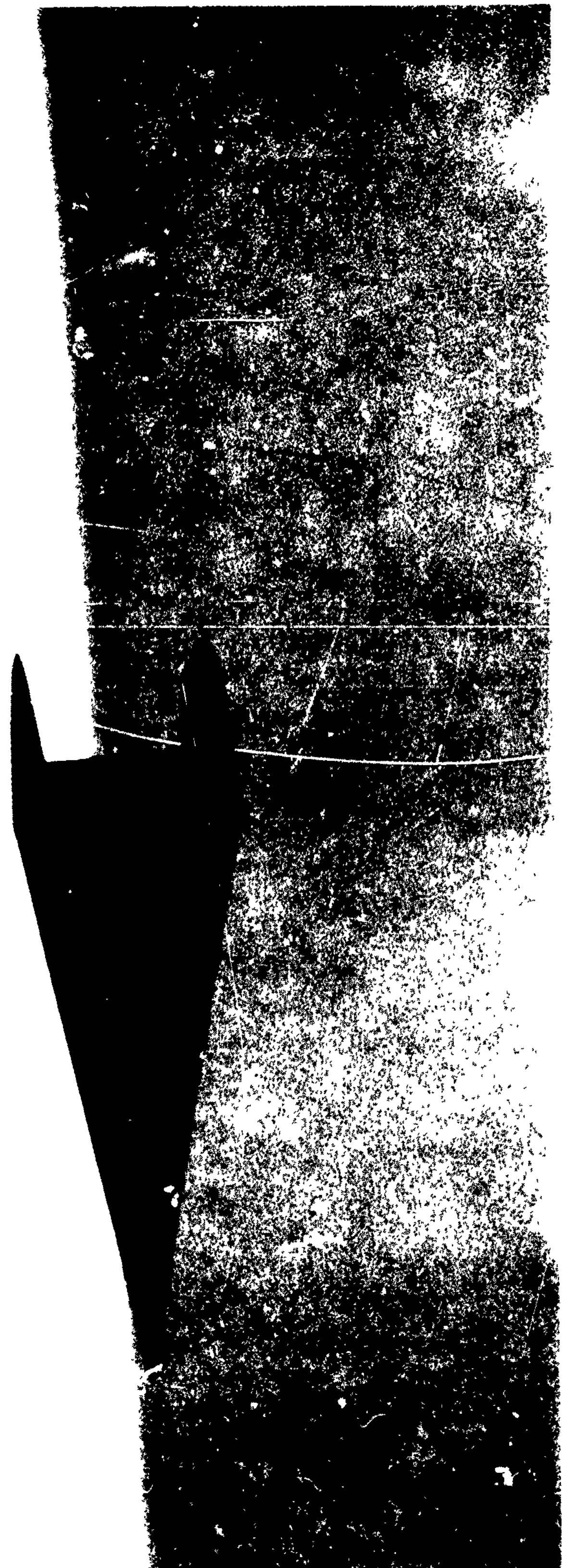


Figure VI

IV Task B - Using the four input angles, a simple routine is used to determine the azimuth and elevation angle to each vertex. This enables us to compute the co-ordinates of each vertex using the equations shown in expressions (1), (2), and (3).

The location of each vertex does not effect the format of the data so that the four objects are stored in the online program. As a new field-of-view is selected, the vertices and other required data are computed, this is inserted into the formatted objects and a new field-of-view is ready in seconds.

V Task C - The visual system receives as input, the azimuth and elevation angles of the pilot's head orientation relative to straight ahead and level line-of-sight. These angles are used to position the hood relative to the viewpoint.

The angles, azimuth and elevation, are used as an input to a program which computes a direction cosine matrix. For this application the roll input is held at zero, and the matrix then yields the orientation of the hood relative to the viewpoint. The location of the hood origin is fixed, i.e., it is the viewpoint location. Therefore, the vector from the viewpoint to the hood origin is always the zero vector.

In implementation, the hood is treated somewhat like a moving model would be except that the calculations are a good bit simplier. For priority purposes, the objects are designed such that there is no conflict between tnem from the viewpoint. A modification was made to the system so that these objects always assumed the highest priority of all the visible objects.

VI Task D - The ASPT system has an online channel assignment calculation. This determines if any object is visible within each of the seven channels. Should it be found that an object is in no way visible in a specific display channel then that object is not processed beyond this point for that channel. This yields an obvious savings in edge processing through the special purpose hardware.

This algorithm is somewhat straightforward. The boundaries or outline of the visible area for each channel are described to the system by a set of vectors. Each vector is a unit normal to the plane containing the boundary of the channel and the viewpoint. Figure VII shows a standard pentagonal view window (channel) with Normal $\overline{N}_1$ derived from edge #1 and the viewpoint.

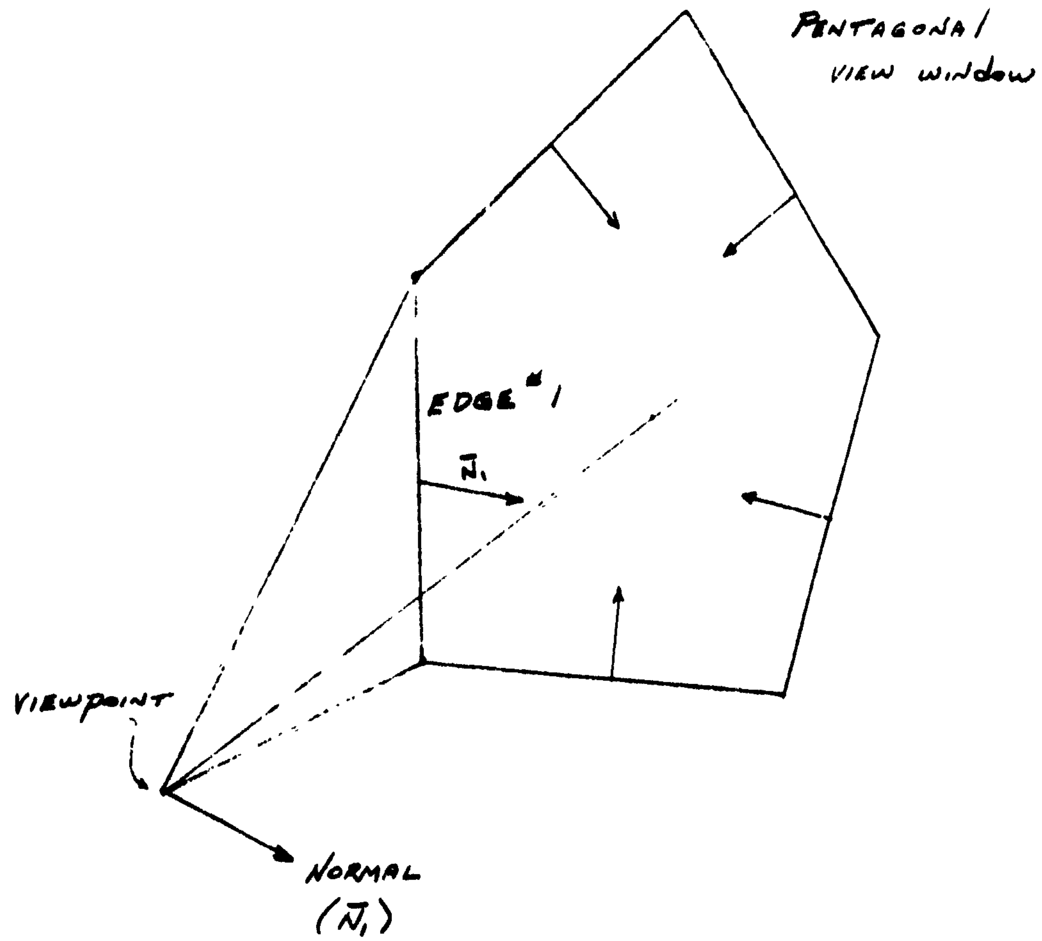

PENTAGONAL
VIEW window
EDGE # 1
$\vec{N}_1$
VIEWPOINT
NORMAL
($\vec{N}_1$)

Figure VII

Recalling some vector mathematics, a point in space is on the same side of the plane as a normal is directed if the dot product of a vector from the viewpoint to the point in question, and a normal to the plane, is positive. In ASPT, a point is visible within a window if this dot product is positive for all five edges of the pentagon.

To detail this test a bit more, the testing is done for each and every object that is potentially visible. Each object is described to the system, for this test, by the location of the center of a sphere circumscribing the object and the radius of this sphere.

The testing per object then becomes:
If the dot product of the vector from the viewpoint to center of the sphere enclosing the object with the normal to each boundary plane plus the radius of the sphere is greater than or equal to zero then the object is visible in that view window.

$$\bar{N}_i \cdot (\bar{V}_x - \bar{R}_p) + R_0 \geq 0 \text{ for } i = 1, \cdots 5$$

$\bar{N}_i$ Normal to boundary plane

$\bar{V}_x$ Vector to center of sphere

$\bar{R}_p$ Vector to viewpoint

R_0 Radius of sphere

When a specific area-of-interest is identified by the user, inputting azimuth, elevation requirements, the boundaries of visibility are known. In fact, they are the face normals of the visible faces of the objects making up the hood. In generating the hood it is a data requirement that each face contain its face normal. This normal is computed using the standard cross product approach. There are fourteen visible, from the viewpoint, faces of the hood. The outline of the visible area can be thought of as a fourteen boundary channel or window.

Consider the problem as a channel assignment application. If the dot product for each of the fourteen normals plus the radius of the object is positive, then the object is visible within the area-of-interest. This is expressed as follows:

$$\bar{N}_i \cdot (\bar{V}_x - \bar{R}_p) + R_0 \geq 0 \text{ for } i = 1, 2, \cdots\cdots, 14$$

Then the object is visible within the area-of-interest.

Using a reduced area-of-interest (20^{o} x 20^{o}) the Figures VIII and IX shows the visual effect without using a hood or mask. The tower is shown visible right near the edge of the area-of-interest. The second scene is from a viewpoint such that the tower would be projected just outside the area-of-interest. It is, of course, not visible. With the hood this algorithm functions the same way, as seen in Figure X. Objects obscured by the hood are not processed so that the effective edge density is increased.

An orientation was selected to visibly demonstrate this reduction of data. Figure XI is a photograph of a scene with several buildings shown around a runway. The use of the area-of-interest of 20^{o} x 20^{o} around the line of sight clearly shows, in Figure XII, the runway and large surface objects but the buildings not within the area-of-interest have been eliminated from view.

VII Task E - The horizon projection through the hood yields a visual reference when used in conjunction with the area-of-interest. In the ASPT system, the horizon is not an edge as such but is projected as a result of the manner in which surface fading is accomplished. Fading is the ASPT simulation of fog, the gradual modification of the gray shade of objects and surfaces towards the gray shade of the fog as a function of fog density, range to the faded point, and orientation.

The surface fading is accomplished late in the processing, since it is done at the element rate. Effectively, when the range to an element is infinite, that is the horizon. Therefore, the problem was only to treat the hood as a surface in terms of fading.

Range to the surface or sky is computed from the line, element number assuming two flat parallel planes, a ground plane and sky plane. Positioning an object other than on these planes still results in fading range computed under the planer assumption.

This was accomplished by assuring that the hood objects were guaranteed to obscure all other objects and surfaces. Then, the hood objects were processed by surface fading thereby yielding the horizon through the hood.

The accompaning Figures XIII and XIV show various orientations of the viewpoint and the horizon being displayed through the hood objects.

VIII Task F - Area-of-interest horizon tracking is accomplished by monitoring roll and pitch angles of the viewpoint relative to the environment co-ordinates. These inputs are used to compute the orientation of the hood relative to the viewpoint by means

Figure VIII

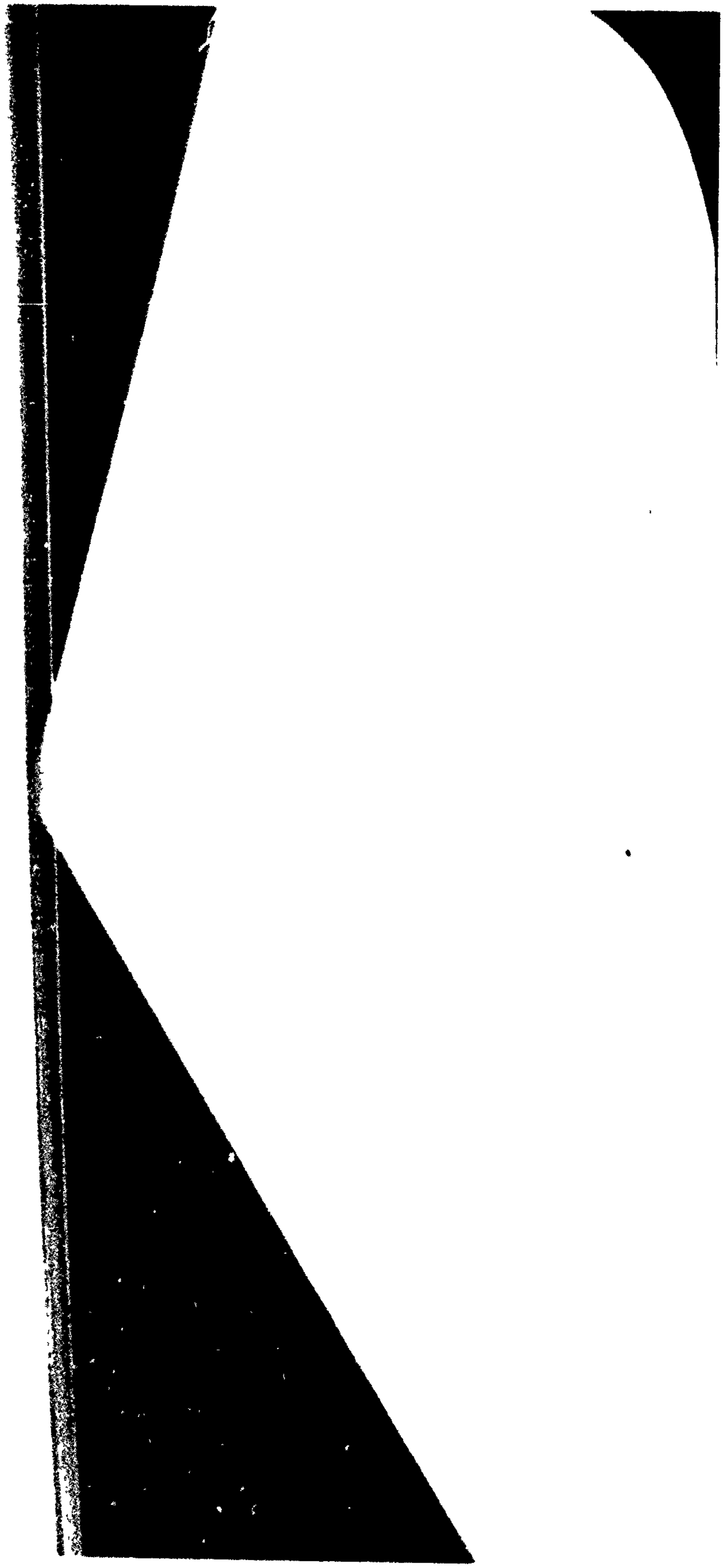


Figure IX

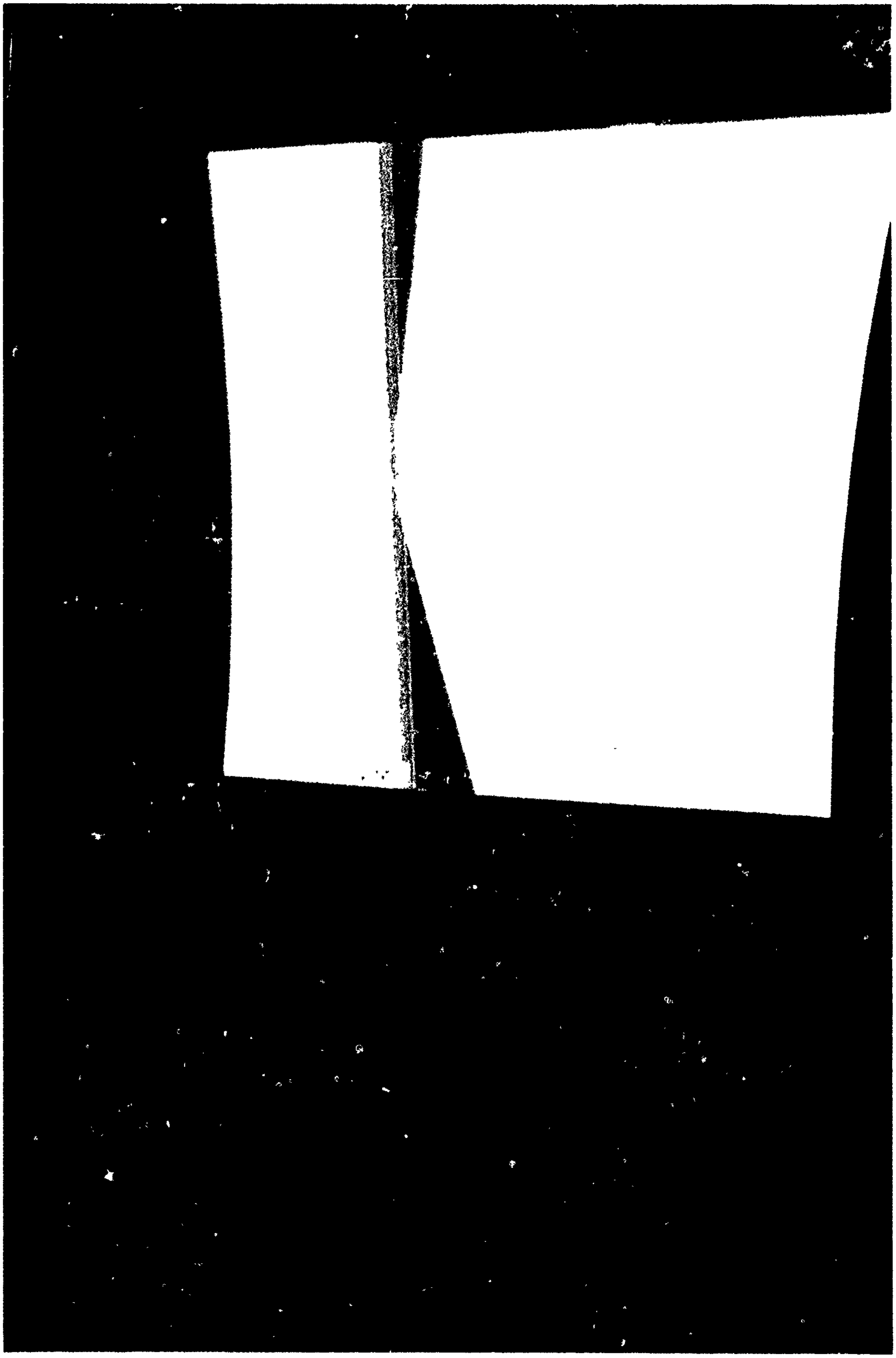


Figure X

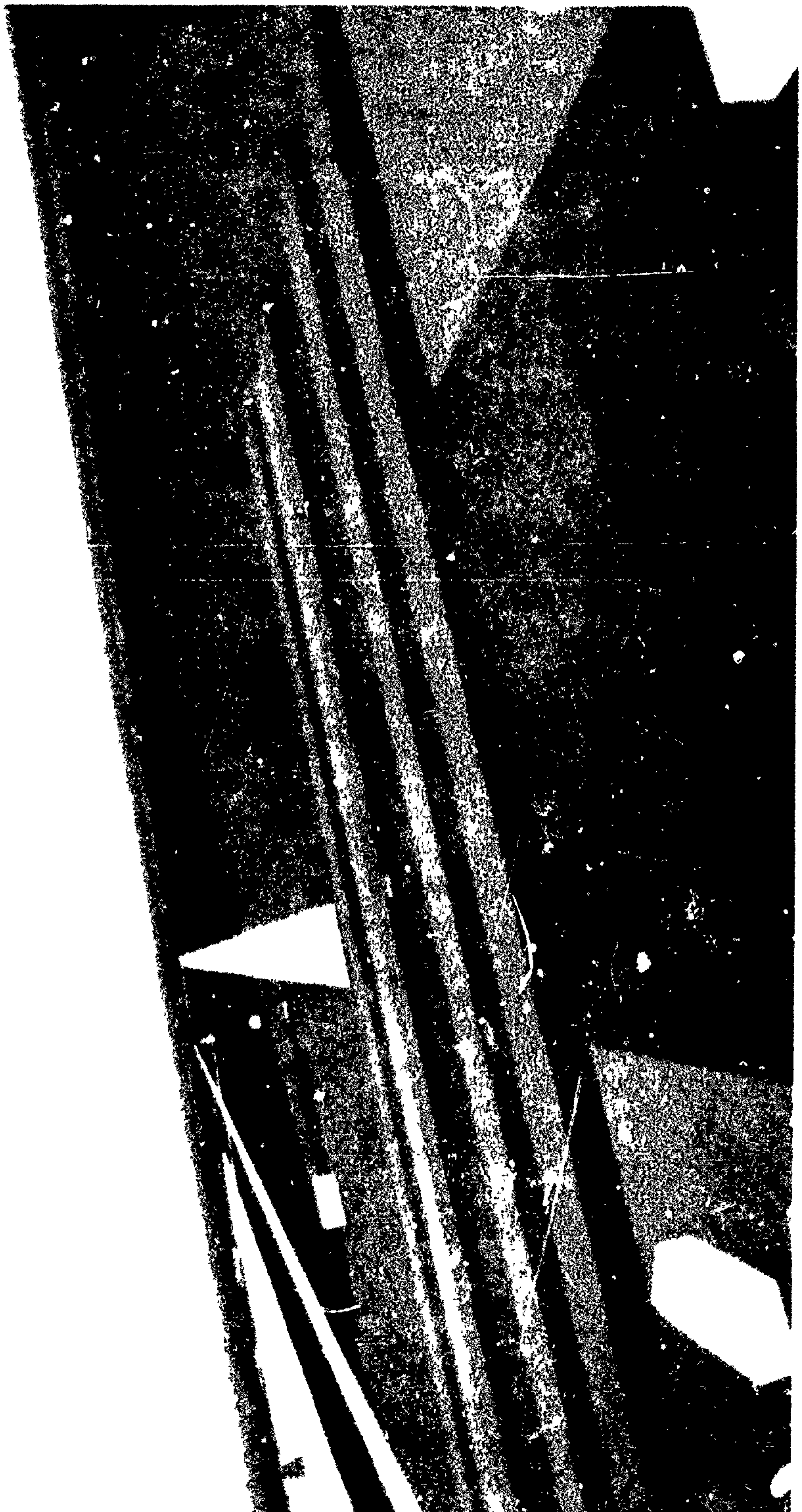


Figure XI

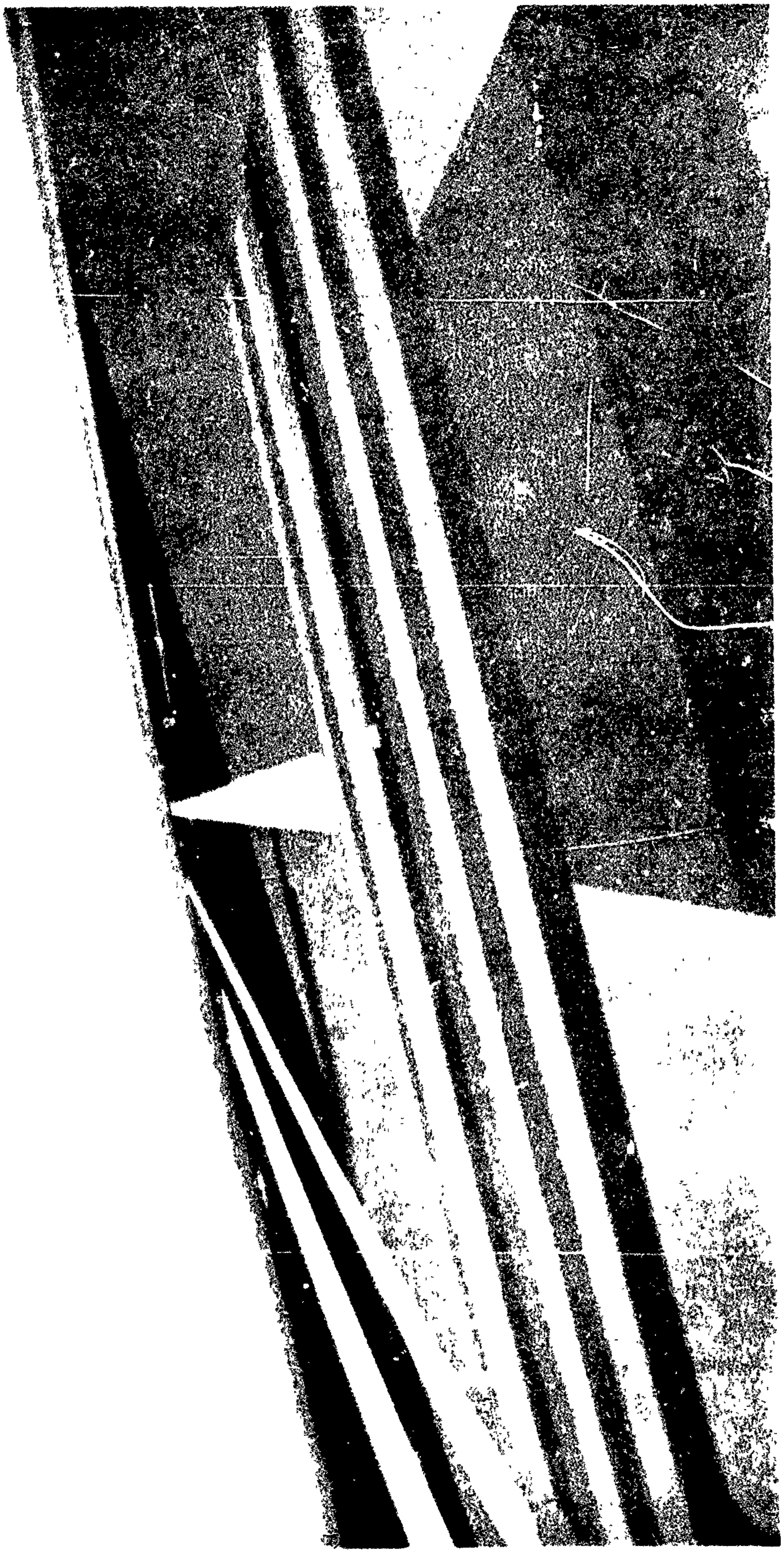


Figure XII

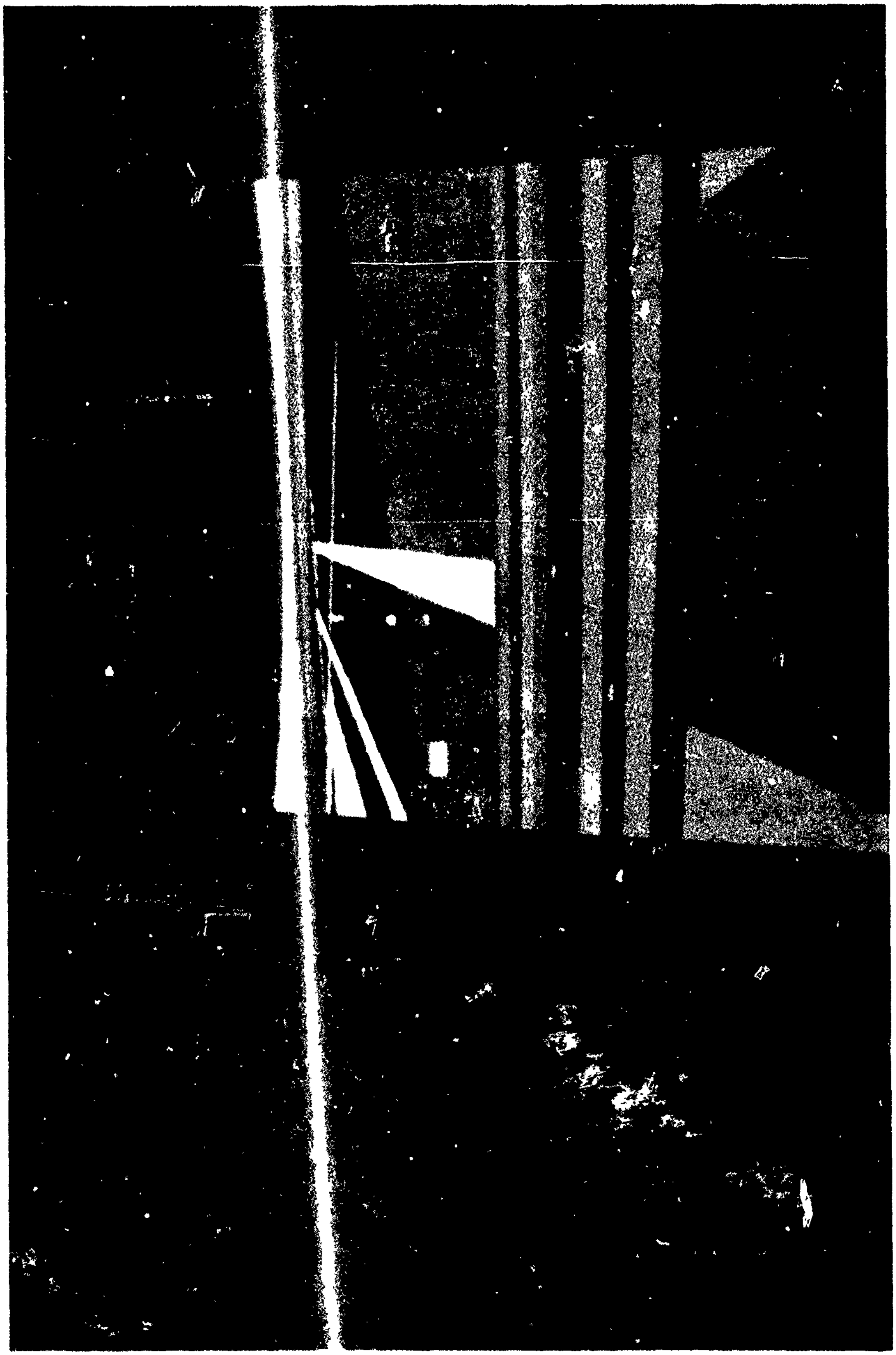


Figure XIII

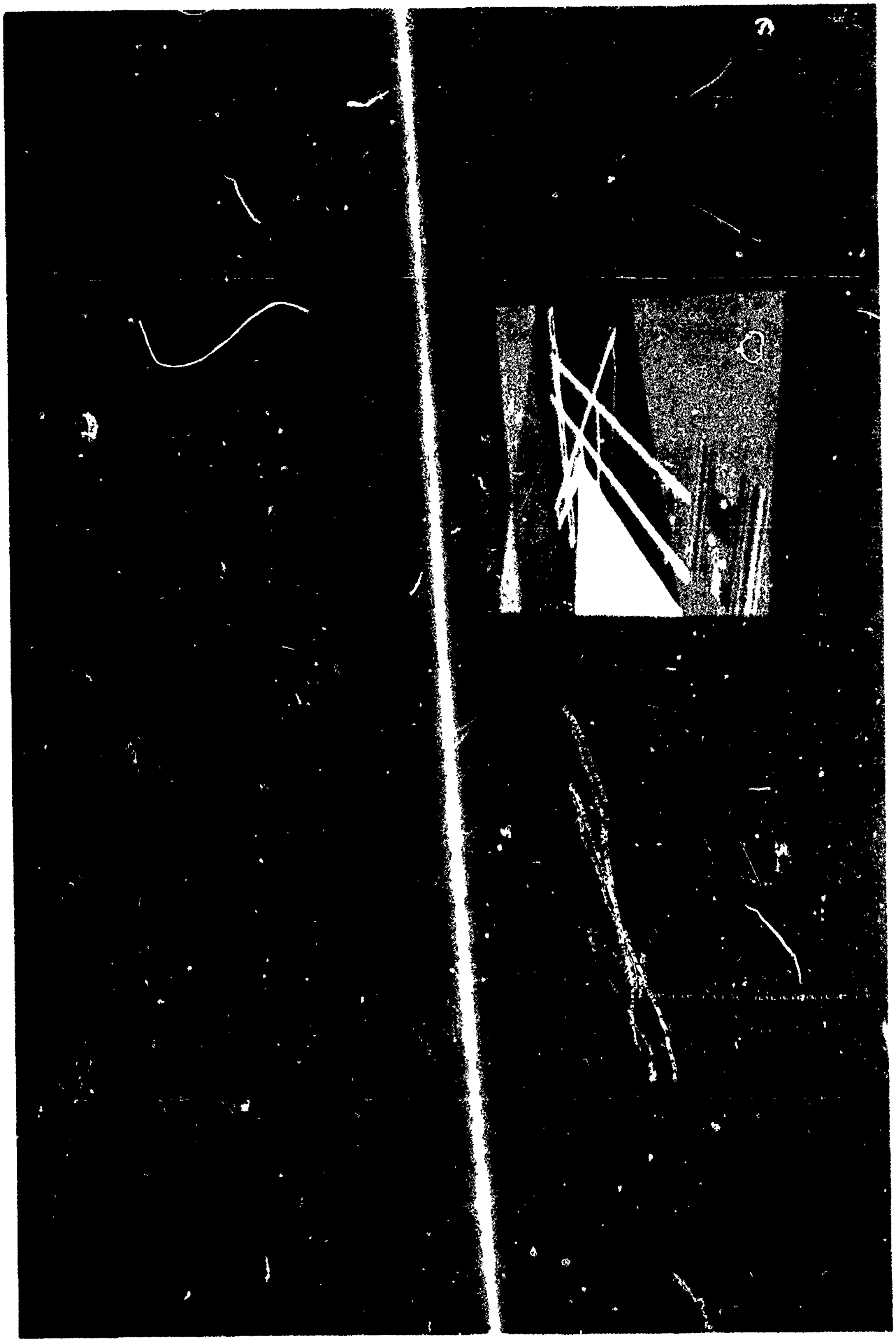


Figure XIV

of a direction cosine matrix. This was not additional work since the head sensor inputs were used in the same manner earlier. The result was a hood which tracks the horizon in roll and pitch, but maintains forward looking yaw relative to the viewpoint.

The three orientations of the hood and horizon shown in Figure XV demonstrate this capability. The top figure is the hood/horizon projection with either algorithm. The center figure shows the visual effect with the horizon tracking the hood while the bottom figure fixes the hood level with the horizon as computed.

CONCLUSION

The AOI capabilities are currently in use for research projects on the ASPT system. The variable field-of-view and area-of-interest capabilities are just two of the many ASPT applications lending themselves to support flying training research.

ACKNOWLEDGEMENT OF SPONSORSHIP

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Air Force Systems Command

United States Air Force

Brooks AFB, TX 78235

The algorithms described were implemented on the Advanced Simulator for Pilot Training located at the Air Force Human Resources Laboratory Flying Training Division, Williams AFB, AZ. The photographs and film report were made in conjunction with the Air Force Human Resources Laboratory Flying Training Division.

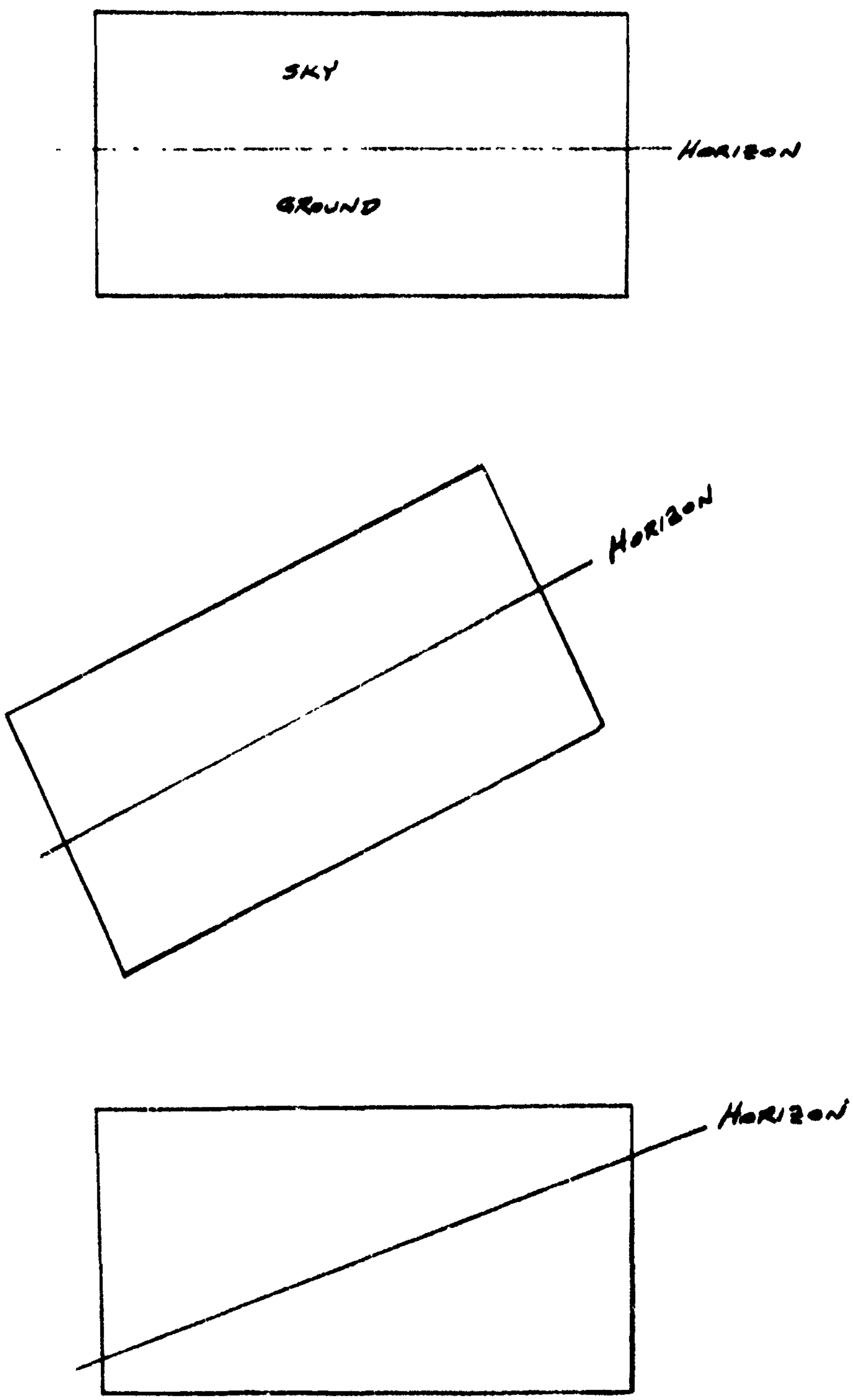

Figure XV

A NEW HORIZON PROJECTOR DESIGN

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Design Engineer
Vought Corporation
Dallas, Texas

PRIMARY RESPONSIBILITY: Lead Design Engineer for Vought R&D Simulation Facilities

PAST EXPERIENCE: Joined Vought Corporation, the Astronautics Division, in 1960, as a Design Engineer on the Dyna Soar Program. Worked on many spare programs primarily in Human Factors Design and Human Engineering.

Became the Mechanical Systems Project Engineer on the Scout Program at NASA Langley.

Worked for Tracor, Inc., as a Project Engineer in Aircraft Electronic Countermeasures. Taught mathematics at the University of Texas and worked as a Research Engineer at the Balcones Research Center in Austin, responsible for experimental design.

Rejoined Vought in 1975 as a Design Engineer in training equipment.

EDUCATION: B.A. Mathematics and Physics - Texas Christian University - 1961.

B.A. Philosophy of Science - University of Texas - 1972.

Graduate Studies - Industrial Engineering - University of Texas at Arlington.

A NEW HORIZON PROJECTOR DESIGN

Robert C. James
Vought Corporation

Spherical screen simulators have become increasingly popular for aircraft training and research. In order to provide a dynamic and realistic environment, sky/earth projectors are utilized to generate a horizon, ground plane and sky details. As the simulated aircraft performs, this projector - gimballed in 3 axes of motion - projects a scene that is a powerful visual cue. These horizon projectors represent an important and vital part of the simulator, their reliability, maintainability, simplicity and realism should be as great as possible.

The idealistic projector concept would consist of a spherical transparency containing a point light source. This projector would be capable of 3 axes of motion duplicating the aircraft attitude. One half of the sphere would be decorated with generalized terrain scenery as viewed from a high altitude and the opposite hemisphere would be sky blue with light patches simulating cloud formations. The two poles of the transparency would represent the zenith and nadier while their conjunction - a great circle in the transparency - would represent the horizon. The combination of the transparency and point light source constitutes a shadowgraph projector which would cast colored shadow imagery on the spherical screen.

The ideal location for this projector would be the center of the spherical screen. At this location the shadowgraph imagery would be undistorted. Unfortunately, the pilot of the simulated aircraft would have to view this imagery from the same location or his perspective would be distorted.

Most advanced horizon projectors designed to date have departed, by necessity, from this idealistic and perhaps simplistic approach. Because the projector is gimballed the sky/earth transparent hemispheres must be separated to provide space for the gimbal mechanism. Since the observer and the projector cannot occupy the same space at the same time, they must be separated. The universal choice is to locate the observer at the center of the spherical screen and displace the projector.

These departures contribute considerably to the complexity of any projector design. Two light sources are required and some mechanism must be provided to translate these light sources as a function of the gimbal rotations to eliminate any distortion. This translation mechanism must fix the light source at some particular radius and

direction relative to the center of the projector transparencies. Usually a three axis servo system is employed inside the housing joining the two transparencies which also contains the yaw drive mechanism. This three-axis translation mechanism or positional servo must be controlled by the simulator computer. Each axis necessitates a drive motor, transducer, mechanical linkage, gears, electrical wiring fed through slip rings, a computer interface, and computer software. As the wiring passes through each gimbal the complexity increases. A typical horizon projector is shown in Figure 1.

In early 1976 the decision was made to install a spherical screen visual system on the Vought Large Amplitude Moving Base Simulator (LAMBS). Part of this program was the design, fabrication and installation of a new horizon projector. It was believed that the usual projector design could be simplified by eliminating the internal 3-axis translation servo that positions the point light sources. This would eliminate many internal mechanical and electrical components, reduce the number of electrical wires, reduce the size of the slip ring assemblies, reduce weight and eliminate a serious maintenance problem. All of this could be accomplished by using the pitch and roll gimbal rotations to translate the light source through appropriate linkages. Intuitively, the light position is a function of the gimbal rotations and assuming:

- The attitude of the horizon projector spherical transparency is positioned to display the desired attitude of the horizon on the spherican screen.

- The distance from the pilot's eye at the center of the spherical screen to the center of the horizon projector transparency is fixed and constant.

- The projector is located above and behind the pilot in the XZ plane of the spherical screen coordinate axes.

As shown in Figure 2 by similar triangles,

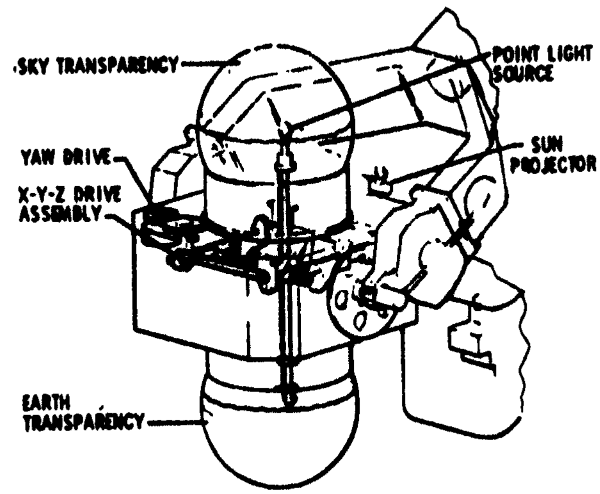
$$\Delta OPH \sim \Delta O'P'H'$$

and given: $OO' = D$

$O'P = d$

$O'H' = r$ (radius of transparency)

$OH = R$ (radius of spherical screen)



A TYPICAL HORIZON PROJECTOR

FIGURE 1

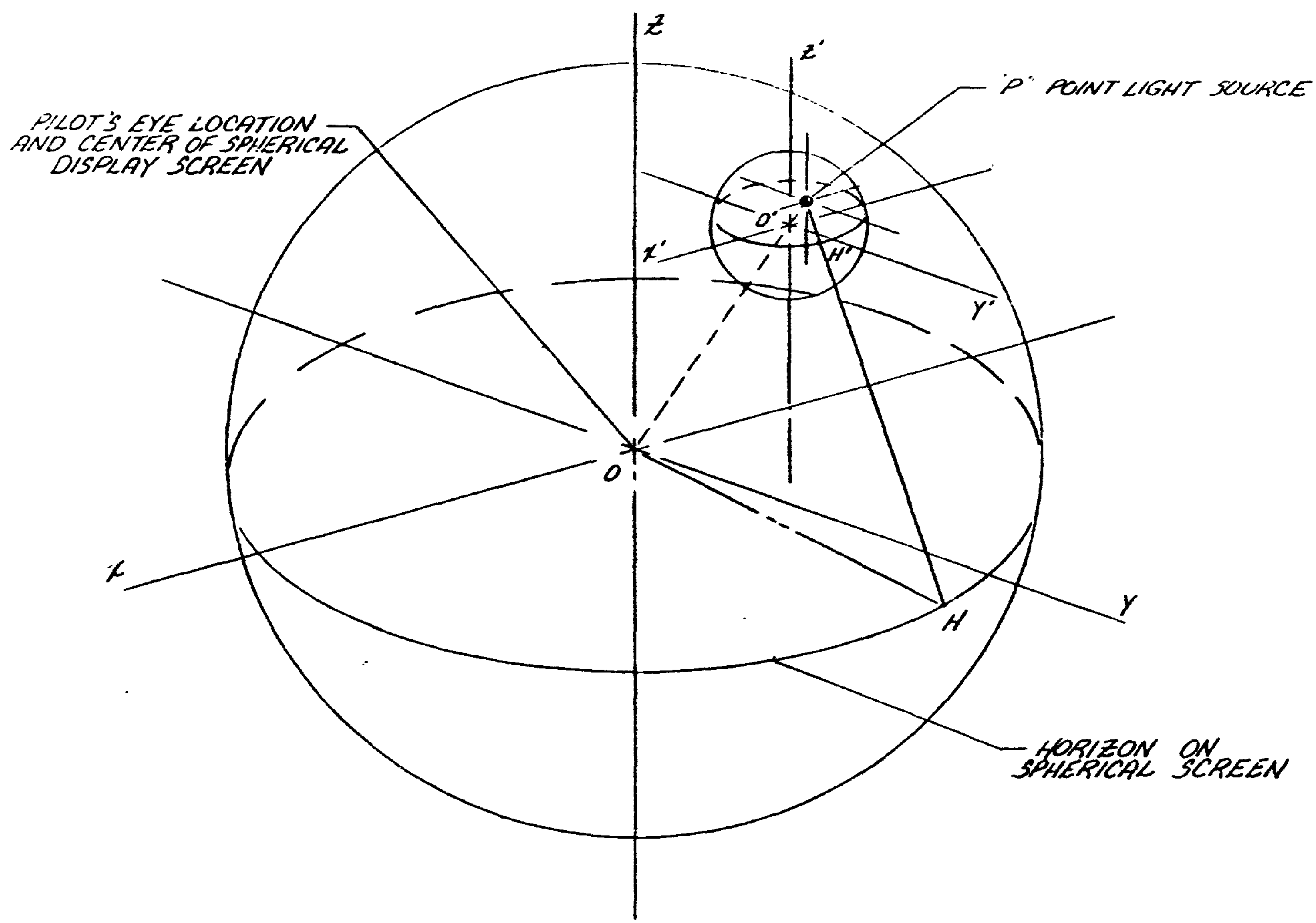

PILOT'S EYE LOCATION AND CENTER OF SPHERICAL DISPLAY SCREEN
"P" POINT LIGHT SOURCE
HORIZON ON SPHERICAL SCREEN
Z
Z'
O'
X'
H'
Y'
O
X
Y
H

Figure 2

knowing

$$\frac{R}{OP} = \frac{r}{d}$$

and

$$OP = D + d$$

then

$$d = \frac{r(D+d)}{R}$$

However, r/R is a constant independent of attitude and

$$d = C_1(D+d)$$

$$d = C_1D + C_1d$$

$$d = \frac{C_1}{1-C_1} D$$

Since $C_1/1-C_1$ is a constant and D is fixed and constant then d is a constant; independent of the attitude of the projector. It can be stated from this analysis:

- o If a point light source is fixed at P, then all points on the transparency will be mapped into the spherical screen without distortion.

- o The distance from the center of the transparency is constant and determinable, dependent solely on the distance from the center of the spherical screen.

- o This is true of any attitude (pitch, roll or yaw) of the horizon projector.

Knowing this, the only task remaining was to design an appropriate linkage mechanism that would produce the appropriate motion. The projector was located inside the spherical screen and the amount of motion was determined. It should be noted that the locus of all points of the center of the translation linkage describes a sphere. In fact, the lights themselves describe spheres as the projector is rotated 360 degrees in pitch and roll. Figure 3 shows a profile view of the final design. Figure 4 shows a view of the projector looking directly aft along the roll axis. Figure 5 is a section view in the XY plane looking down on the projector

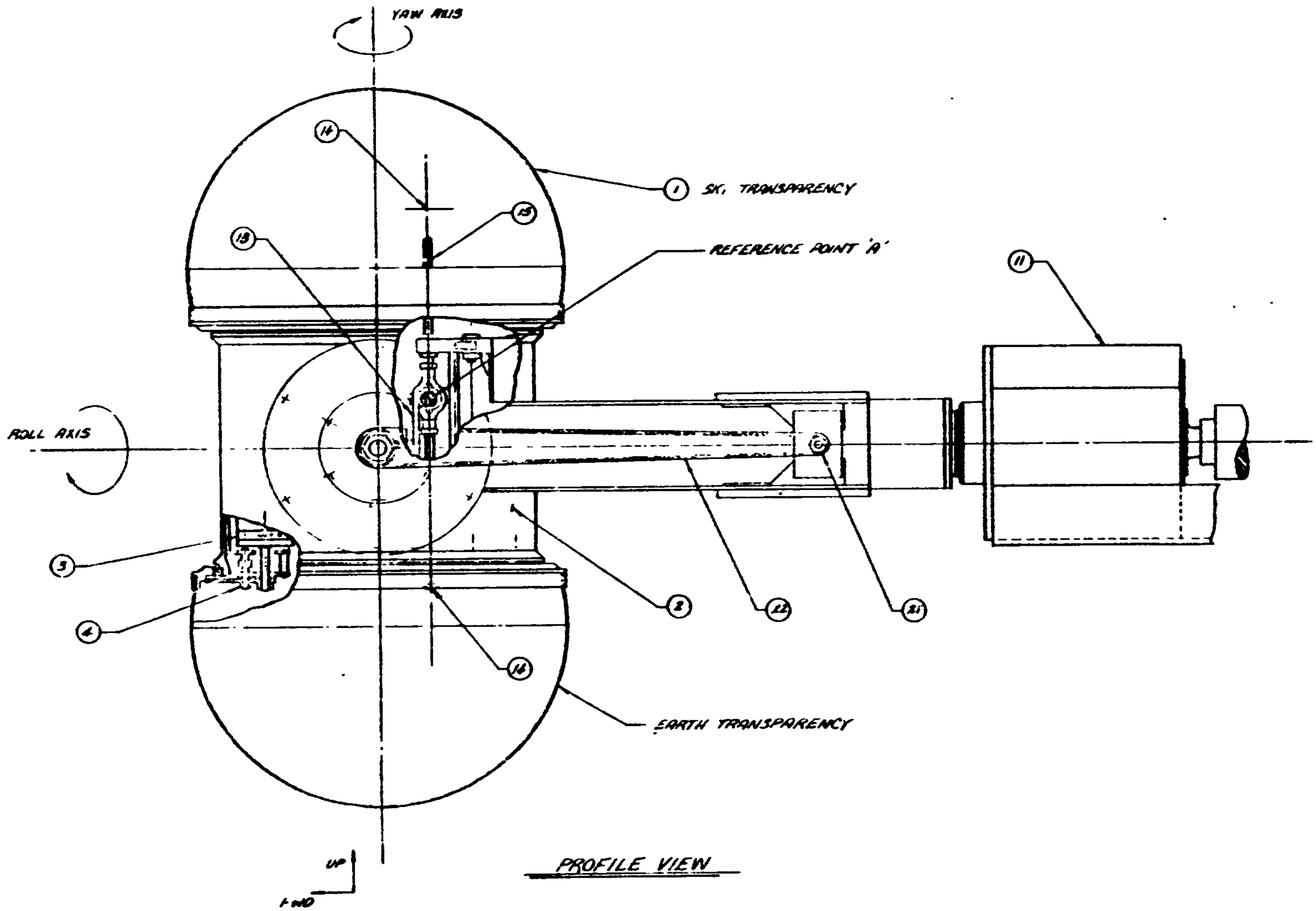

YAW AXIS
ROLL AXIS
SKY TRANSPARENCY
REFERENCE POINT 'A'
EARTH TRANSPARENCY
PROFILE VIEW
UP
FWD
1
2
3
4
11
13
14
15
16
21
22

Figure 3

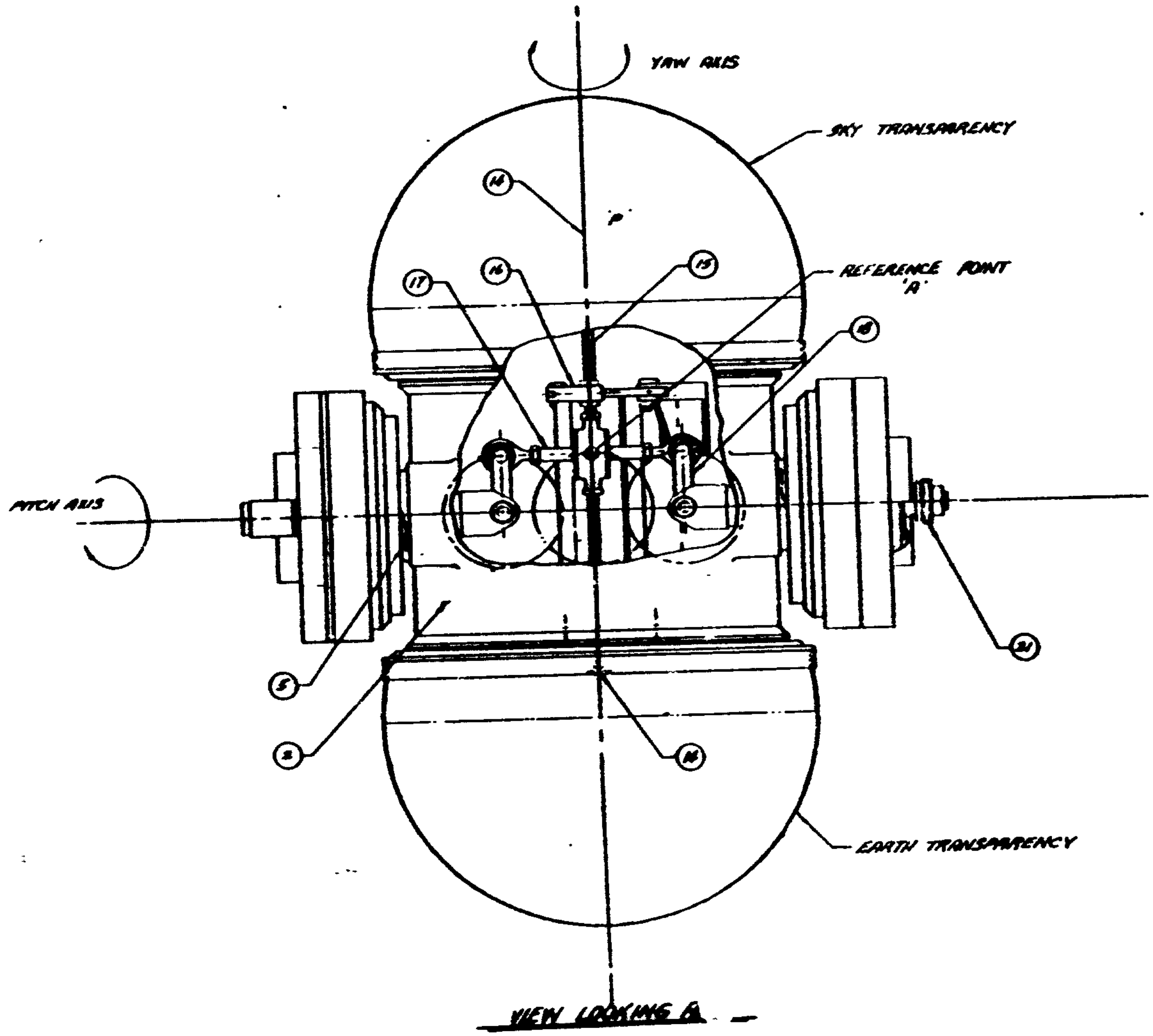

YAW AXIS
SKY TRANSPARENCY
REFERENCE POINT 'A'
PITCH AXIS
EARTH TRANSPARENCY
VIEW LOOKING A

Figure 4

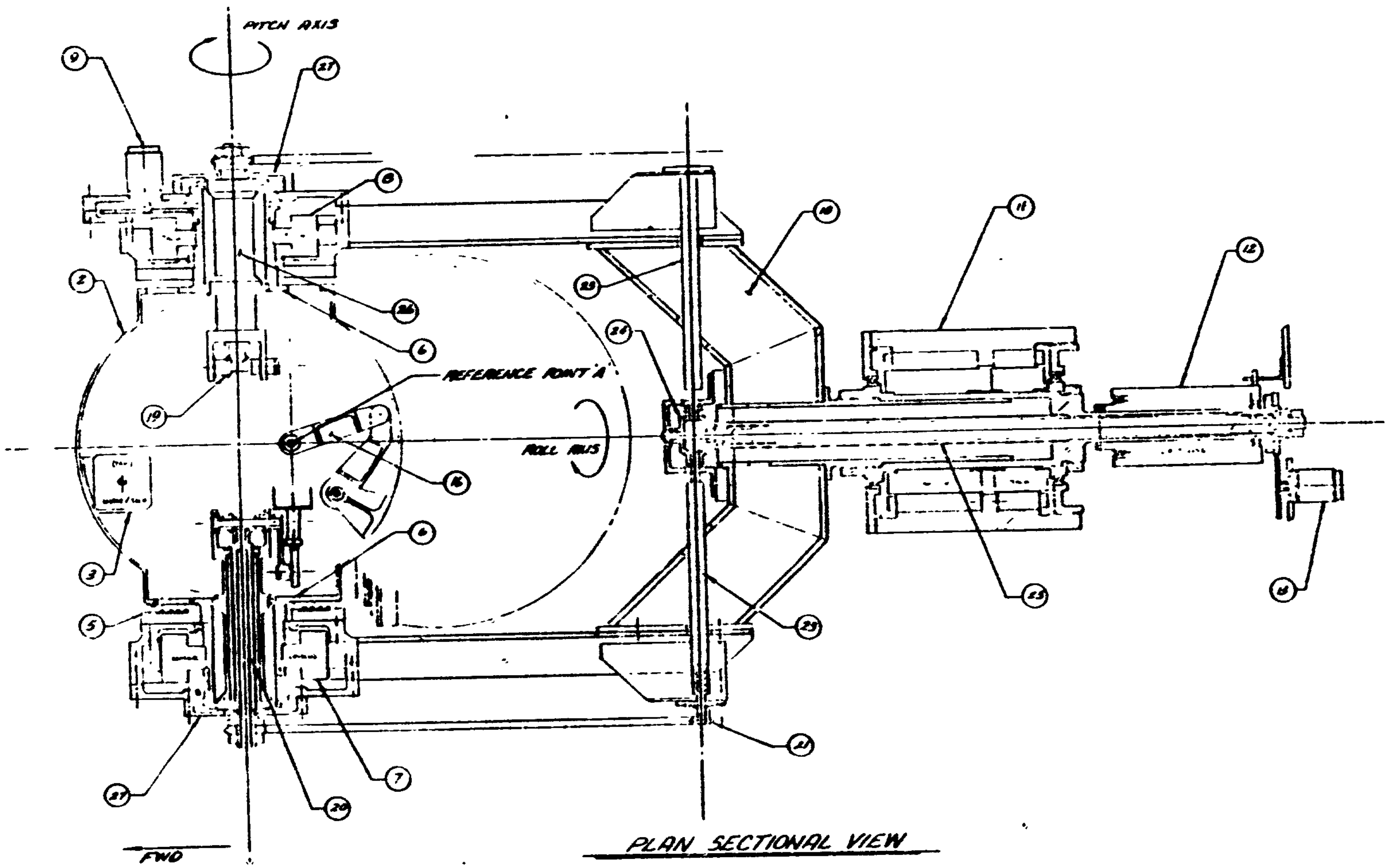

PITCH AXIS
REFERENCE POINT A
ROLL AXIS
FWD
PLAN SECTIONAL VIEW

Figure 5

HORIZON PROJECTOR PARTS IDENTIFICATION

1. Hemispherical Transparencies
2. Pitch Axis Housing
3. Yaw Axis Drive Servo
4. Yaw Axis Drive Gear Train
5. Pitch Yaw Slip Rings
6. Pitch Axis Axle
7. Pitch Axis DC Torque Motor
8. Pitch Axis DC Tachometer
9. Pitch Axis Synchro
10. Roll Axis Gimbal Fork
11. Roll Axis DC Torque Motor/Tachometer
12. Roll Pitch Slip Rings
13. Roll Synchro
14. Point Source Lamps
15. Light Source Support Rod (Lamp Drive)
16. Support Rod Guide Assy (Lamp Drive)
17. Roll Connecting Link (Lamp Drive)
18. Roll Motion Crank (Lamp Drive)
19. Roll Motion Bevel Gears (Lamp Drive)
20. Roll Motion Input Shaft, Pitch Axis (Lamp Drive)
21. Roll Motion Input Drive Sprockets (Lamp Drive)
22. Roll Motion Input Drive Belt (Lamp Drive)
23. Roll Motion Grounding Cross Shafts (Lamp Drive)
24. Roll Motion Grounding Bevel Gears (Lamp Drive)
25. Roll Motion Grounding Shaft (Lamp Drive)
26. Pitch Input Shaft (Lamp Drive)
27. Pitch Input Grounding Plate (Lamp Drive)

and translation mechanism.

The gimbal system is a typical 3-axis system which rotates the sky and earth hemispherical transparencies in 3 orthogonal rotational axes - roll, pitch and yaw. The Yaw Axis Bearings for the hemispherical transparency drives are attached to the Pitch Axis Housing. The Pitch Axis Housing provides the Yaw Servo system enclosure and most of the lamp drive components. It also separates and supports the bearings for the hemispherical transparencies. The Yaw Axis Drive Servo is attached to the Pitch Axis Housing and rotates both transparencies in yaw. A DC Torque Motor powers the Yaw Axis Drive Gear Train. There ia tachometer beedback and synchro control, to position the transparencies.

On each side of the Pitch Axis Housing are two extension tubes that act as the axles in the pitch axis. These axles are attached to the rotors of the Pitch Axis DC Torque Motor and DC Tachometer. Coupled to the right hand axle through a gear train is the Pitch Axis Synchro.

The Roll Axis Gimbal Fork has on each side the field housings of the Pitch Axis Torque Motor and Tachometer, and provides the structure to couple these to the Roll Axis DC Torque Motor/Tachometer Assembly. This assembly attaches to the support structure for the Horizon Projector.

Electrical signals are fed through the Yaw Axle Slip Ring at the Yaw Axis and the Roll Axle Slip Ring at the Roll Axis. A Roll axis synchro is coupled through a gear train for position control.

The foregoing described parts and assemblies describe a typical three-axis drive system that generates the rotational motion for the projector. The Lamp Drive System, however, is not typical but a unique and novel approach.

The Lamp Drive System is designed to accomplish two basic functions:

1. Fix the Lamp Drive System Reference Point A (see Figures 2, 3 and 4) relative to the gimbal axis as the gimbal system rotates in pitch and yaw.

2. Translate this fixed point motion (relative to the gimbal axis motion) to the light sources in order that they might have the correct motion relative to the sky and earth transparencies as they rotate in pitch and roll.

The net result is the light sources remain fixed at a constant distance and direction relative to the center of the sky and earth transparencies and these transparencies rotate about the 3 orthogonal axes. This constant distance and direction is relative to the spherical display screen coordinate system. It should be noted that the centers of the transparencies do translate as a result of the 3 axis gimbal rotations because of their separation to provide gimbal mechanization. This translation produces a small error that is compensated for by a small increased separation in the point light sources.

The reference point A is the center of the Roll Connecting Link which is moved in a circular motion by the two Roll Motion Cranks. These Roll Motion Cranks are driven by bevel gears which, in turn, are driven by the Roll Motion Shafts. The Roll Motion Shafts are rotated by the input drive sprockets and drive belts. The driving sprockets are attached to the grounding bevel gears and the roll grounding shaft. This shaft is mechanically grounded at the end opposite the bevel gears. This shaft is then stationary as the Roll Axis Gimbal rotates about it. The final result of this power train is an equal and opposite rotation of the Roll Motion cranks as the Roll Gimbal rotates. Reference point A remains fixed at a particular offset and direction independent of Roll Gimbal motion. The drive shafts for the Roll Motion Input Cranks are supported in a trunnion which is an integral part of the Pitch Input Shaft. This shaft is mechanically grounded to the Roll Gimbal Fork at the Torque Motor and Tachometer Housings by the Pitch Input Grounding Plates.

The throw radius of the Roll Motion Input Cranks and their offset to the rear of the gimbal rotation point are sized according to the spherical display screen radius, the radius of the hemispherical projection transparencies and the location of the horizon projector gimbal point relative to the pilot's eye (center of the display screen). The required dimensions are based on the required location of P as developed in the previous analysis.

The remaining linkage of the Lamp Drive System is required to transmit the desired position of reference point A to the point light sources. The lamps are connected to a rigid suppord rod which slides in linear ball bushings. The Support Rod Guide Assembly keeps the support rod parallel to the Yaw Gimbal Axis.

The length of the Light Source Support Rod is equal to the separation of the sky and earth transparency centers plus a small added distance to cause the projected horizon lines to meet at the display screen surface.

This unique and novel approach to Horizon Projector Design has resulted in a projector that is much less costly, more dependable, more reliable and much lighter in weight. The Lamp Drive System is a paragon

of simplicity and Vought Corporation design engineers believe the objectives of this design task have been successfully completed.

TERRAIN ELEVATION SIMULATION, A SIGNIFICANT CUE TO GROUNDBASED TRAINING SYSTEM EFFECTIVENESS

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Dr. Robert T.P. Wang, as Section Supervisor of the Advanced Development Group in the Marine Systems Division of Honeywell, Inc., is responsible for the management and direction of research and advanced development projects. These projects span many facets of technology, ranging from applications of fiber optics to distributed processor computer busing, to adaptive control systems, to conceptual development of large-scale trainer systems.

At Honeywell, he has developed data compression algorithms for video data communication systems, data bases for visual and radar simulators, and algorithms for synthesizing visual, radar and sonar signals for groundbased trainers. As a post-doctoral fellow at Stanford University, he participated in a NASA project to develop a real-time video satellite communication system for teleconferencing and educational TV applications. While at Ampex Corp and earlier at IBM, he was involved in a variety of projects ranging from application of an optical data processing system to signal signature recognition, to circuit designs for instrumentation tape recorders, to testing of precision passive, active and electromechanical components.

Dr. Wang received all of his early education in India, including studies towards a B.Sc. (Honors) degree in Physics. He received a B.S.E.E. from the University of Pennsylvania, an M.S. in Engineering from the University of California at Berkely and a Ph.D. in Electrical Engineering from Stanford University.

TERRAIN ELEVATION SIMULATION, A SIGNIFICANT CUE TO GROUNDBASED TRAINING SYSTEM EFFECTIVENESS

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ABSTRACT

The significance of simulating the effects of terrain elevation is developed for both visual and radar simulators. It is shown that although the nature of the cues a terrain elevation simulation provides differ for the two applications, both add significantly to the usefulness of the simulators as training devices.

SUMMARY

Occulting, camouflaging, highlighting, and shadowing by terrain are all significant effects that either enhance or impede the ability of an aircraft pilot, bombardier or navigator to perform his job. Such terrain induced features are very real to the airmen in their typical working environment, and are factors that they must learn to contend with early in their career.

This paper uses the vehicles of visual and radar systems to illustrate how the nature of terrain induced characteristics in the imagery presented to the viewer affects his modus operendi. Consequently, the need to simulate terrain elevation effects to some degree of faithfulness becomes an important concern in developing a trainer that will introduce such effects at an early stage of the training program.

Methods for simulating terrain are discussed for visual and radar simulators. The difference in techniques used for each application are discussed in light of the constraints that drive each application. In conclusion, the needs and status of terrain elevation simulation is discussed for both visual and radar simulators.

(Full text not available at time of publication)

SESSION III

Chairman
Captain Patrick E. O'Gara, USN
Assistant Chief of Staff for Flight Training
for the
Staff of the Chief of Naval Education and Training

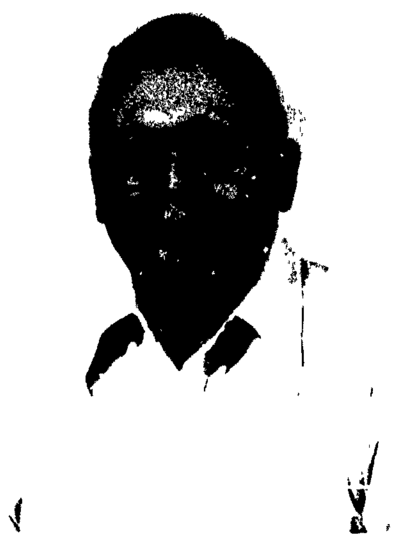
Captain Patrick E. O'Gara, USN

Captain Patrick E. O'Gara, U.S. Navy is presently serving on the staff of the Chief of Naval Education and Training as Assistant Chief of Staff for Flight Training. A Naval Academy graduate, Captain O'Gara was designated a naval aviator in 1953 and has been involved in carrier aviation most of his career. He has commanded two fleet aircraft squadrons, been Executive Officer of the aircraft carrier ORISKANY and Commander of Training Air Wing THREE.

His decorations include the DFC, Bronze Star, five Air Medals, two Meritorious Service Medals, Navy Commendation Medal with Combat V, and various campaign medals.

AVIATION WIDE ANGLE VISUAL SYSTEM (AWAVS)

CGI System



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Mr. Booker was employed by the Martin Company, Orlando, Florida from 1961-1965 logic and computer interface design. In 1966 he joined the Naval Training Equipment Center, as a research electronic engineer - computers. His research interests include computer generated displays both CGI and interactive man-computer interface, real time computer software, and computer system architecture as applied in training simulators. Mr. Booker is a member of Eta Kappa Nu, Tau Beta Phi, Sigma Xi, and IEEE Computer Society.

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CGI SYSTEM

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Abstract

Characteristics and planned applications of the Navy AWAVS Computer Generated Imagery (CGI) System for development of environment modeling and generation of visual data bases are described. The CGI system consists of three major subsystems: a non-real-time Camera Station, an interactive Data Base Development Facility, and a real-time CGI Image Generator. The system is scheduled for delivery to the Naval Training Equipment Center Computer Laboratory by the General Electric Company during October of this year.

Introduction

The Navy AWAVS is the Naval Training Equipment Center experimental facility for design and development of aircraft flight simulator wide angle visual display systems. The key concept on which the AWAVS development is based is an ability to easily reconfigure equipment to provide special equipment configurations required to investigate the many complex pilot training tasks. The approach results from the recognition that no single wide angle visual system concept exists which promises to be cost effective and satisfy projected visual cue requirements.

Two major hardware systems are being acquired for AWAVS. These are the Conventional Takeoff and Landing (CTOL) and Vertical Takeoff and Landing (VTOL) simulators, each consisting of a flight simulator, visual display, and image generation subsystems. Display subsystems from either the CTOL or VTOL simulator may be configured with image generation subsystems from the other simulator to provide visual system configurations required for the variety of visual cue requirements. The CGI system is being acquired as an additional image generation subsystems for either the CTOL or VTOL configuration.

CGI system characteristics and some of the potential applications of parts of the system for environment modeling and generation of visual data base environments are described in this paper. The CGI system consists of three main subsystems: (1) a non-real-time digital image recording system called the

Camera Station, (2) an interactive Data Base Development Facility for creation of visual environments, and a real-time CGI Image Generator to be used as an alternative image source for the area-of-interest projector. Figure 1 shows an artist's concept of the general arrangement of the CGI system equipment. A CGI System Functional Block Diagram showing the main hardware components is shown in Figure 2.

Camera Station

The Camera Station provides AWAVS with a non-real-time image recording facility for production of moving pictures or still photographs. A software emulation of the real-time display system processing algorithms on the general purpose computer provides the necessary simulation to derive pictures from a data base format identical to the real-time system. The non-real-time nature of frame-by-frame computation by the software emulation removes the timing and processing limitations imposed on the real-time hardware, and allows photographs and movies to be made of visual environments containing detail far in excess of the processing capabilities of current real-time systems. Characteristics of future high capacity designs may be simulated in software. Moving pictures may be made from the high density data bases within reach of the new designs. Films made from prerecorded flight paths through the visual environment may be visually evaluated prior to commiting funds for development and procurement. Software simulation of new display algorithms, new system configurations, and design improvements can be evaluated by demonstration of pictures equivalent to the end product prior to making decisions on implementation. Characteristics of sensors such as FLIR or LLTV can be simulated in non-real-time and films made of flights through the data base environments as demonstrated by Dr. Bunker of General Electric for the Human Resources Laboratory.(1) Feasibility and potential limits of high-density, visually rich environment simulations may be assessed using the Camera Station equipment.

Camera Station Hardware

Camera station hardware consists of a Color Image Recorder, Model D-47, manufactured by Dicomed Corporation linked with direct memory access to the Digital Equipment Corporation PDP 11T55 general purpose computer with drive controls for film advance and color filter selection. System resources utilized in the Camera Station configuration are shown in the Functional Block Diagram of Figure 3. The central component is the general purpose computer because it controls the image recorder, computes the exposure for each picture element according to the

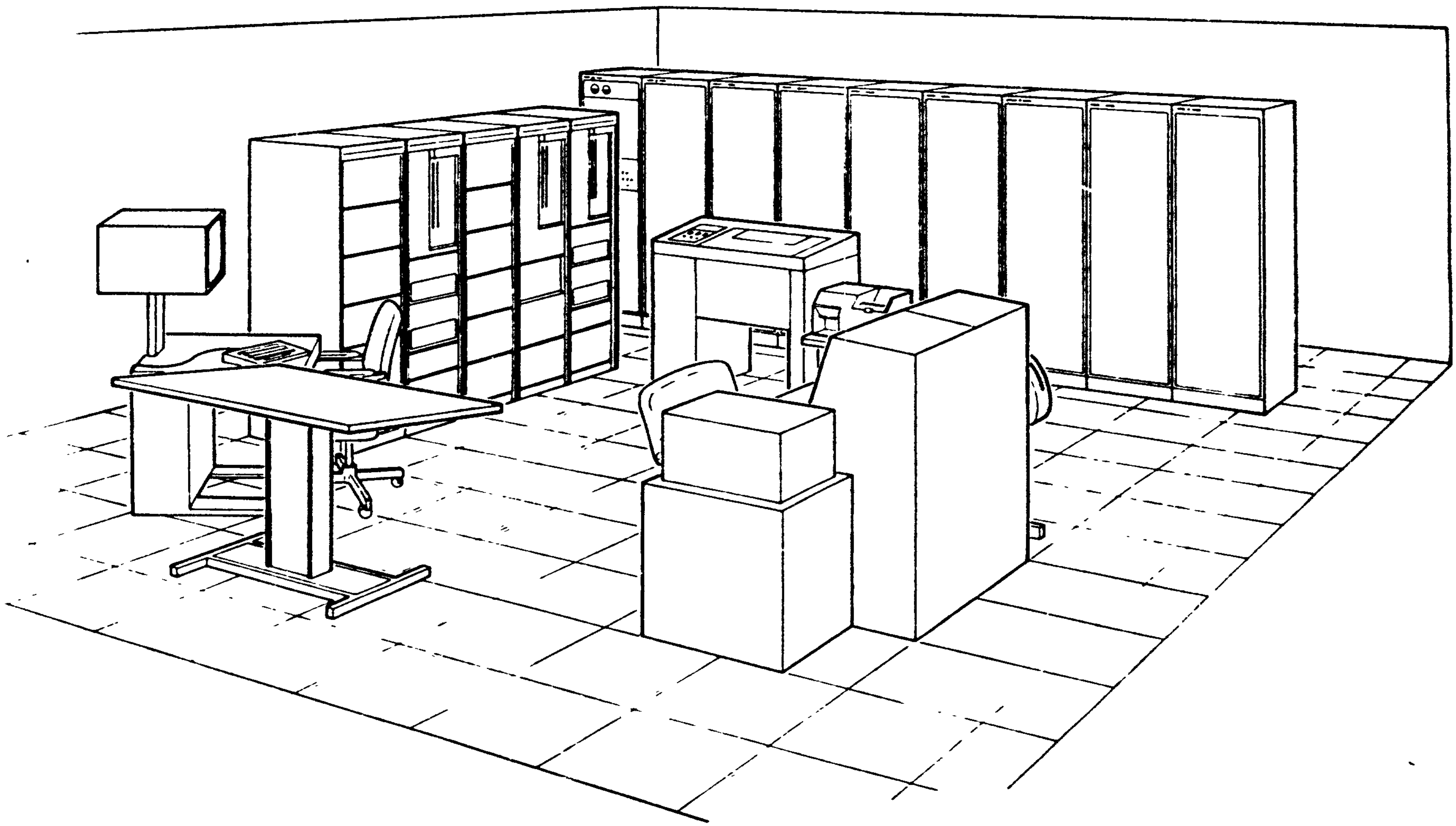

Figure 1. Artist's Concept of the AWAVS-CGI System

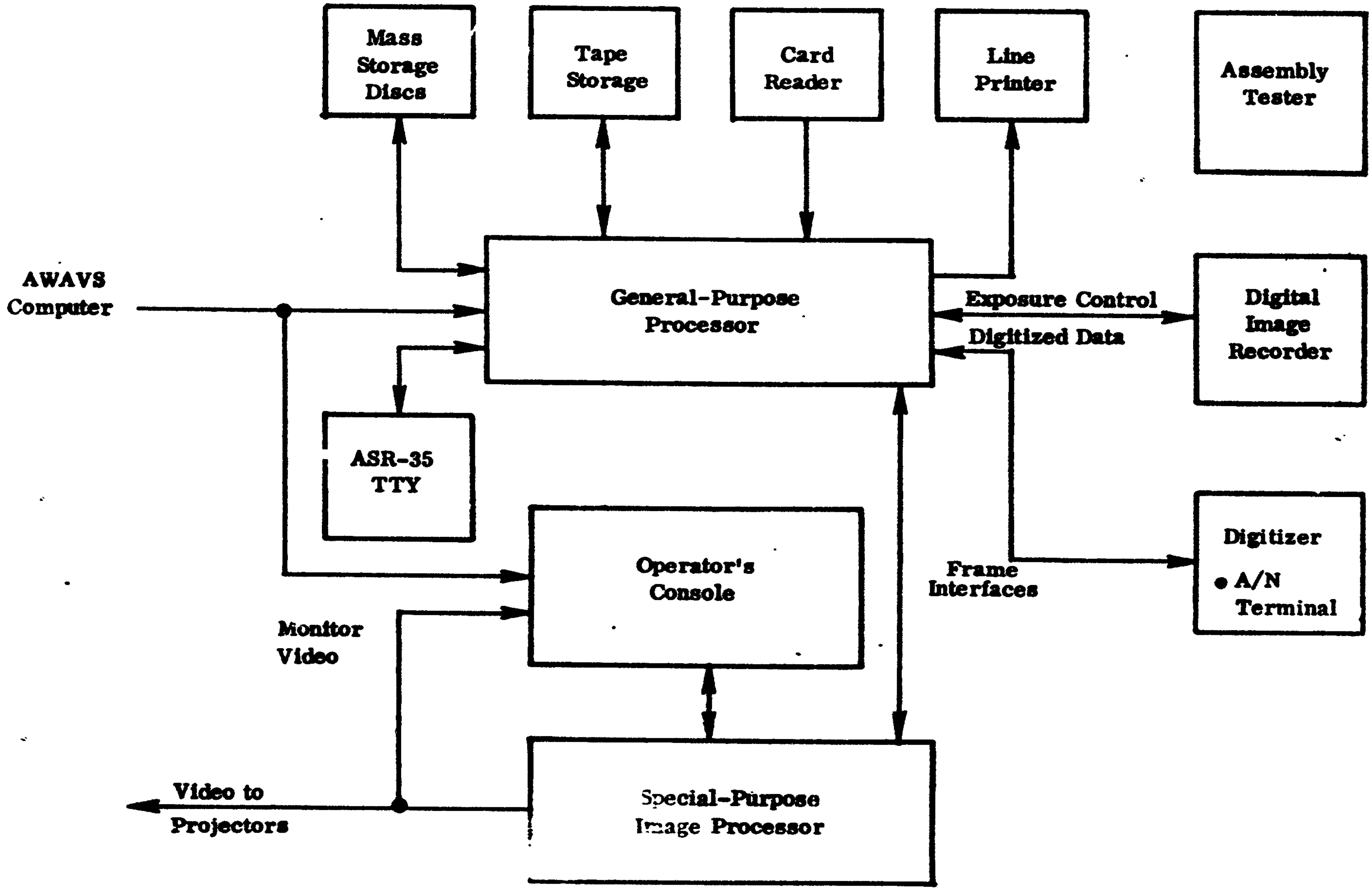

Figure 2. AW... ...GI System Functional Block Diagram

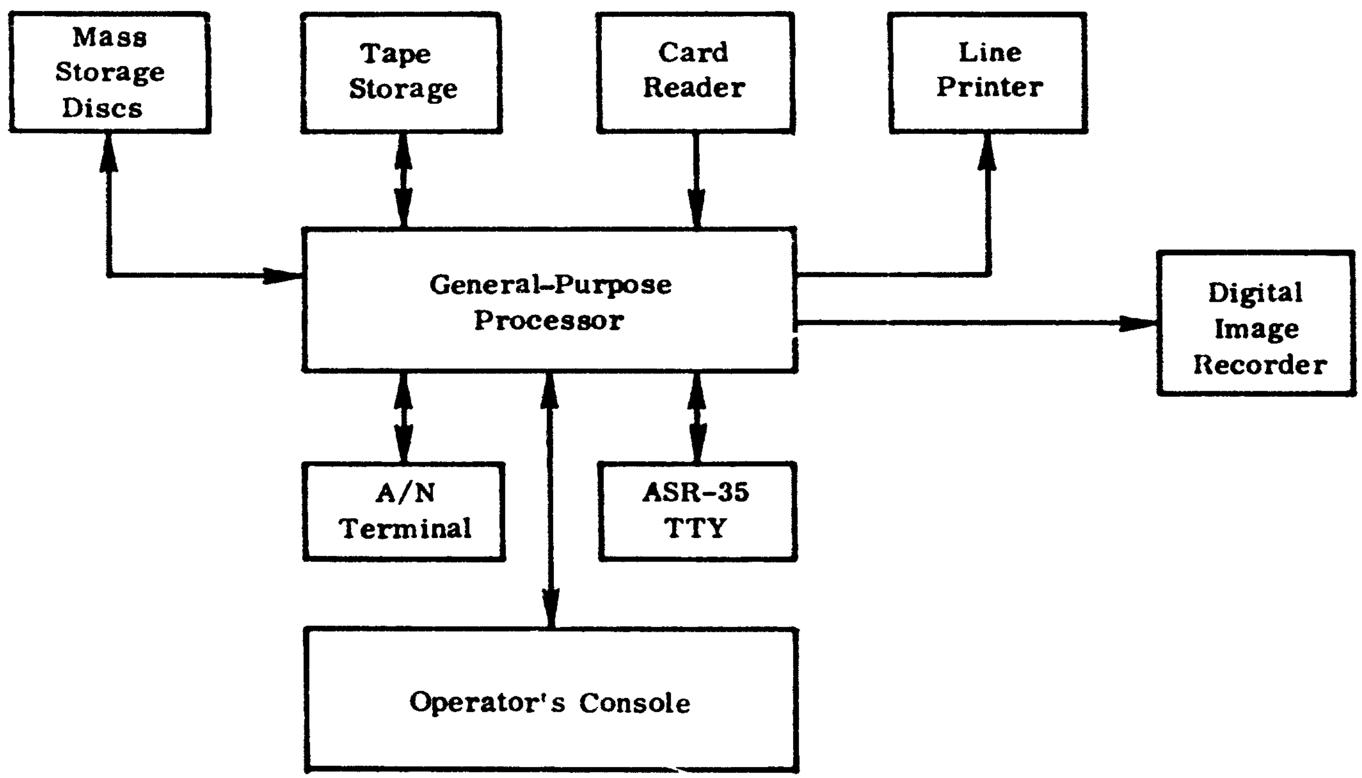

Figure 3. AWAVS Camera Station- Functional Block Diagram

real-time algorithm being simulated, repositions the CRT electron beam, changes filters, and advances the film for the next frame. The mass storage disks, magnetic tape unit, line printer and other peripherals perform important roles in software development and control of the Camera Station configuration. Table 1 shows a concise listing of the external characteristics of the Camera Station.

The digital image recorder is a high resolution random scan CRT controlled from the general purpose computer. A picture or motion picture frame is generated by sequentially exposing each picture element (pixel) under control of the GP computer. A raster scan television monitor may be simulated by sequentially addressing columns and rows of the high resolution CRT plotting matrix. Exposure is controlled by the simulation algorithm in the GP computer program. Color pictures are generated by making three successive exposures with a different filter for each color. Random scan calligraphic images may also be simulated since random horizontal and vertical positions can be externally commanded. A calibrated bias control is provided for adjusting the range of the CRT beam intensity.

Camera Station Software

The heart of the Camera Station system is the software package developed for the general purpose computer. Fully automatic production of film sequences from recorded view point position and attitude definitions on disk or magnetic tape is required. This is necessary since long frame generation time for the high resolution mode requires off-shift or off-line operation of the camera station to generate reasonable length film strips. Motion sequences can be generated either by reading successive viewpoint definitions from memory or magnetic tape or by computing new values of flight-path locations from a vehicle math model within the Camera Station computer.

Software to be developed for the Camera Station can be divided into control and simulation program segments. Control segments initialize automatic sequences, interface with the user, control input/output to the image recorder, and control the sequence of processing of the simulation segments. Simulation segments are software implementations of the real-time CGI system processing algorithms.

Each major hardware algorithm will be simulated in one or more subroutines. This provides a convenient means of altering an algorithm to determine the effect of the change on other processing functions and on the final scene. New algorithms

TABLE 1. CAMERA STATION SYSTEM CHARACTERISTICS

Plotting Matrix—Low Resolution —Medium Resolution —High Resolution	1024 × 1024 Picture Elements 2048 × 2048 Picture Elements 4096 × 4096 Picture Elements
Variable Resolution —Full Format Exposure —Reduced Format Exposure	 Integral Fractions of Above Any Non-Integral Values of Above
Resolution	3000 Lines
Film Format	100 Feet 35mm Magazine Polaroid Film Holder Model 405
Exposure Levels	256
Exposure Range	Extrachrome 6115 - 2.0D Plus X Pan 4147 - 1.8D
Exposure Uniformity	±0.35D Maximum
Exposure Control	Yes
Recording Speed—Black/White —Color	5.5 Min } Nominal Maximum Time for 16.5 Min } High Resolution
Interface Signals	Data Control Commands Recorder Status Codes
CGI Simulation	Raster Scan or Calligraphic
Data Base	Common with Real-Time CGI
Scene Content Statistics	Yes
Predetermined Flight Path	Yes
Simulation of Real-Time CGI	Yes—Nonreal-Time
Software Status—Image Recorder —Raster Scan Simulation	Modify and Update Modify and Update

and new design approaches can be simulated in software to verify conceptual correctness before implementation in hardware. Processing operations from frames I, II and III of the real-time hardware are called sequentially into core to process the simulated data base environment in the same way the real-time system processes its data. Data base format is the same as that processed by the real-time system with intermediate formats between segments passed between major frames similar to those generated by the special purpose hardware.

Scene statistics are generated in the simulation segments. Such numbers as total numbers of edges, potentially visible edges, maximum edge crossing per scan line, scan line number on which crossings occur, maximum lister depth (simultaneous priority levels present), maximum video assembler entries may be printed out as desired. The software mode has provisions for wide variations in processing with none of the real-time limits. Environments containing varying richness in scene content and edge detail may be processed sequentially by the non-real-time software. Processing parameters such as field-of-view, number of TV lines and elements, illumination effects, curvature effects, texturing, etc., may be specified by the operator via control segments. The only apparent limit on scene detail is table size on disk memory.

Data Base Development Facility

Increasing capacities of real-time CGI systems dictate corresponding increases in size of the data base environments which drive them. As generation capacity increases, the numbers of potential training applications multiplies, and the scope of simulations envisioned grows. All of this points out the necessity for efficient, highly automated methods for creating data base environments. Environments containing the equivalent of up to half-million edges, or more, are now being proposed. Advances in present methods of data base generation are absolutely essential if environments of this complexity are to be developed. In a like manner, we find that more efficient utilization of capabilities of existing systems are demanded as the range of applications of installed systems increases.

The need for improved data base generation methods was recognized as an essential requirement for the AWAVS CGI system procurement. Originally, the requirement for an off-line capability similar to those described by Sutherland[2] and Schnitzer[3] was envisioned. Recently, a more highly interactive, on-line mode has been recognized as desirable and was incorporated in the data base development facility. The off-line mode is analogous to programming in assembly language

using an interactive terminal. It is used in original data base creation and digitization of maps and drawings. The on-line mode provides an analogy to use of an interactive debug package using a terminal and computer console, and is useful in debugging and fine tuning visual environments on the real-time system television monitors.

Off-Line Data Base Development Facility

The off-line facility will be used to generate original digital data, manipulate and transform stick figure format pictures, complete data base specifications, and compile real-time data bases using the general purpose computer and a commercial drafting system (APPLICON) digitizer and display terminal. Changes to existing environments may be incorporated in the off line mode through the terminal and then recompiled for operation on the real-time system.

Two methods are used for generation of data base definitions. One originates data from original form using the digitizer. The other manipulates, modifies, rearranges, and organizes data already defined with a data base management system.

Data in original form such as scaled drawings, sketches, photographs, contour maps, tabular data, magnetic tape formats are digitized into the APPLICON data base format. Commands available for operator selection include display any of six orthographic views, singularly or any two simultaneously, display isometric, dimetric, trimetric, and general axonometric projections or perspective views. Changes made in one view are automatically made in all other views. Tablet commands available include the ability to display a rectangular grid, move indicated portions of a drawing, magnify or scale parts of it, copy shapes, build new objects from old ones, or working from two views, add shapes in one plane and move or rotate them out of the plane to appear in any desired orientation. Interpreting hand-drawn manipulation operations provides customized operator controls. Textual data may be affixed to shapes, components, vertices graphically for identification or other purposes. Flying eye views of the 3D graphics may be obtained under operator control.

The off-line data base management system has two libraries, an object library and a model library, which are used to generate environments. Basic object definitions are contained in the object library. New models are defined from existing object data by reorientation, scaling, and modifying using the storage display terminal and digitizing table. Much modeling time is saved by providing random access of data records through individual directories in each library. Programs are provided to

copy complete files or libraries from file to file or disk to disk. Modeling is broken into 3 hierarchies: object data, model definitions, and environment definitions. A model book of previously created objects allows new objects to be generated by creation of a copy which then requires minimum specification of new information. Model book objects are accessed by page number and then specified by dimensions, location, orientation and tonal information. Existing pages include cylinders, cones, blocks, gable-roof buildings, shed-roof buildings, pyramids, windows, doors, roads specified by center lines, vertices width, etc. The operator needs no concern with any bookkeeping functions, object topology, or call up from disk; all of which are handled automatically by the software.

The off-line data base development facility hardware configuration is shown in Figure 4. Hardware consists of a 34x44 inch digitizing table with an electronic pen and digitizing puck, a 19 inch CRT storage scope graphic display device with electronic scan hard copy device housed in the keyboard module, and alphanumeric keyboard with an audio confirmation of correct digitizer instruction inputs. A summary of the off-line data base development facility characteristics is shown in Table 2.

On-Line Data Base Development Facility

The On-Line Data Base Development Facility provides a real-time data base debugging and fine tuning capability analogous to the capabilities of an on-line debug package on a typical minicomputer. The on-line facility uses the image generator and console monitors to display and modify the environment data base. Control of a pointer visible on the television monitor by a joystick or by teletype alphanumeric input allows identification of models, objects, faces, or vertices by the console operator. These entities can then be modified by software programs according to operator commands input from the console.

Discussions with data base modelers have indicated the off-line digitizing technique for data entry into the system does not completely give a fully satisfactory man-machine interface throughout the data base creation process. Visually verifying the relative position or orientation of objects in the environment and other fine tuning performed by the modeler requires an ability to alter existing data bases without requiring backtracking to the initial step of the off-line data base creation mechanism.

Hardware modifications to the special purpose Image Generator required to implement the on-line facility were incorporated into the AWAVS CGI system procurement. Those modifications allow the general purpose computer access to internal image generator counts and address pointers. Data provided includes model address, model number, level of detail, face number or point light number.

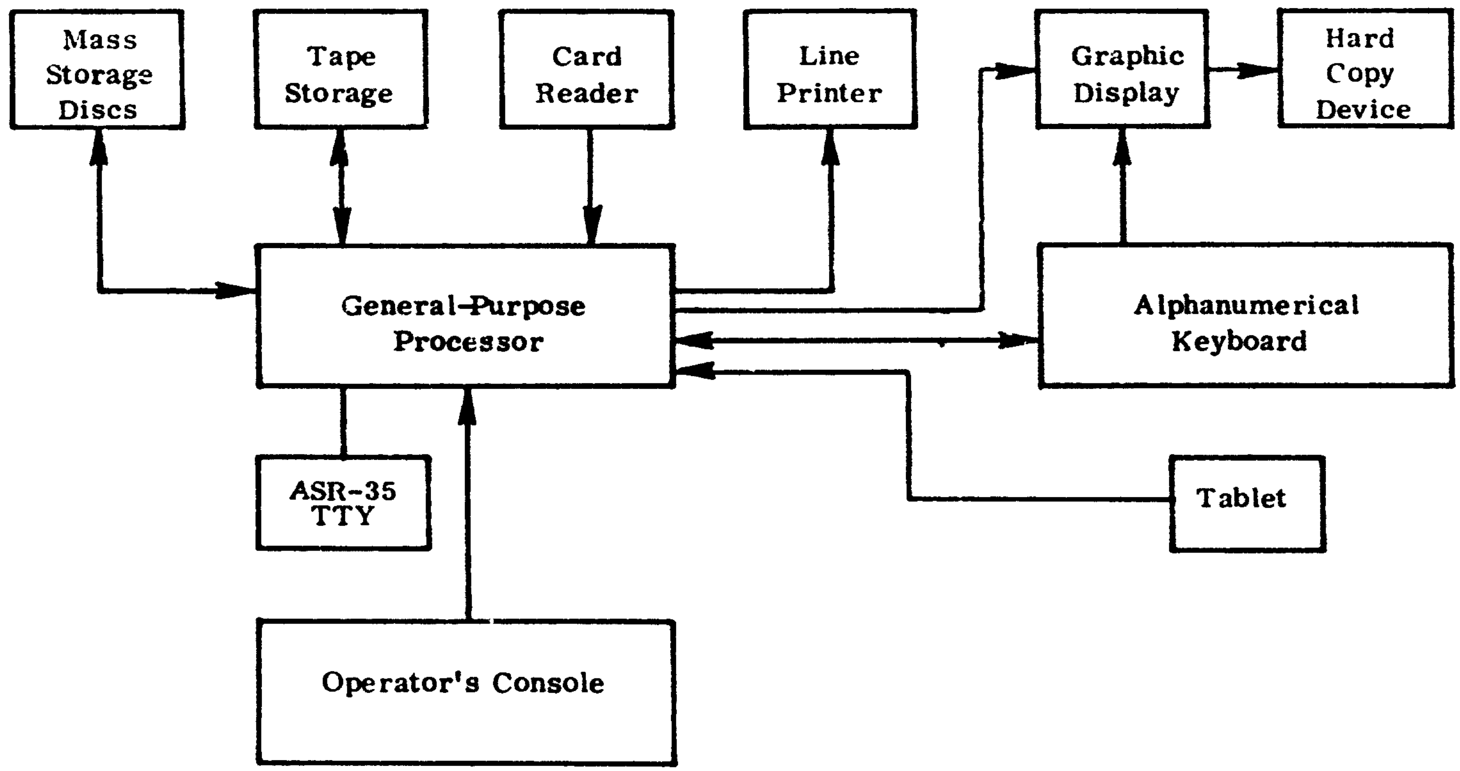

Figure 4. AWAVS Data Base Generation Facility - Functional Block Diagram

TABLE 2. OFF-LINE DATA BASE GENERATION FACILITY CHARACTERISTICS

Tablet	
Size	34 × 44 Inches
Resolution	160 Lines/Inch or 0.00625
Accuracy	±0.003 Inch
Repeatability	±0.003 Inch
Linearity	±0.006 Inch
Repetition Rate	400 Coordinate Pairs/Second
Graphic Display	
Type	Storage Tube
Number Display Points	1024 × 1024
Display Size	19 Inch Diagonal
Storage Time	1 Hour
Luminance	5 Foot-Lamberts Minimum
Characters	94 Types With 2590 to 8512 Total
Keyboard	ASCII Characters
Hard Copy	Yes
Interactive	Yes
View Modification	Rotate, Translate, Stretch, Shrink — Any Axis
Model Book Provisions	Yes
Software—Digitizer	Procured
—Model Book	Modify and Update

The software required to implement an on-line facility has not yet been incorporated into the CGI system contract, but existance of the hardware hooks will enable development of the required programs. The software package would allow objects to be identified, viewed, rotated, translated, geometrically modified or color or intensity changed dynamically as viewed during the real-time mission.

Upon completion of the software package described above, the AWAVS CGI system data base development facility including both on-line and off-line digitizing facility should give the Naval Training Equipment Center the most flexible data base generation tool in existance.

Some of the interactive features planned for the real-time software package are shown in figure 5.

General Purpose Computer Equipment

Because of requirements imposed on the general purpose computer equipment by the interactive functions of the Data Base Development facility and automatic control functions of the Camera Station, the general purpose computer and peripheral devices supplied with the system take on more importance than primarily background functions required by flight simulator CGI systems. A summary of the characteristics of the Digital Equipment Corporation PDP-11T55 general purpose computer and peripherals is shown in Table 3.

Real-Time Image Generator

The real-time CGI system in the CTOL phase of AWAVS will be used as an alternative source of image generation for the area-of-interest projection channel. It is a monochromatic 1000 edge system with characteristics shown in Table 4. During the VTOL phase the CGI system will have color added and edge capacity doubled since present plans call for CGI to be a primary source of image generation. In the present configuration, CGI is a secondary image source since the display system for the CTOL phase was primarily designed for a model board image generator. Resolution of the background channel and area of coverage is too gross for effective use of the CGI image generator since distortions on the spherical screen would be too great. Keystone and horizontal spherical distortion will be corrected for in the CGI area-of-interest mode.

During the early phases of the AWAVS CTOL operation, the CGI system will be available for experiments in environment modeling and interactive software development for the on-line data base development facility. Console monitors are adequate

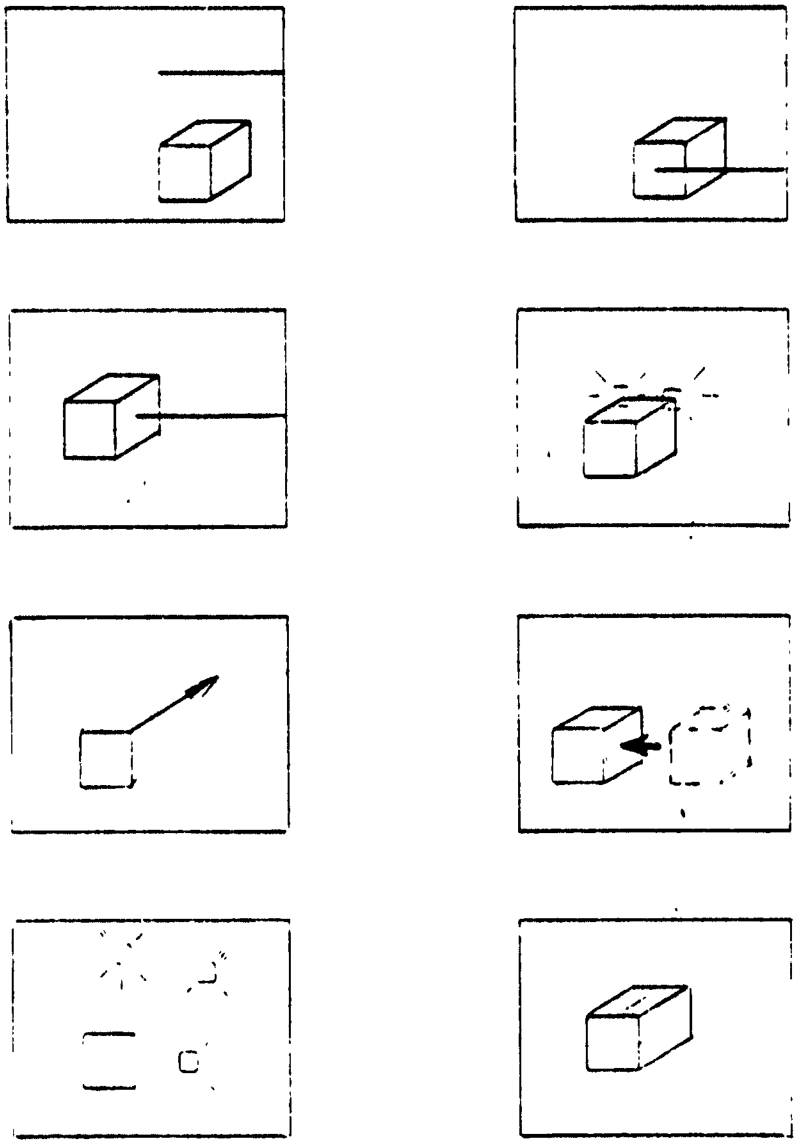

Figure 5

TABLE 3. GENERAL PURPOSE COMPUTER SYSTEM CHARACTERISTICS

Manufacturer/Model	DEC PDP 11T55
Operating System	RSX11-9M
Active Memory	32K Bipolar 32K Core
Worst Case Spare	25 Percent
Clock	Programmable Real-Time
Processor	Floating Point, Hardware Multiply/Divide
Loader	Bootstrap
Power Fail and Restart	Yes
Mass Storage	
Moving Head Discs	44M Word-28 ms Access 1.2M Words-70 ms Access
Tape	9 Track
Worst Case Spare	50 Percent
Line Printer	300 LPM, 132 Columns
Card Reader	EIA Standard 80 Column Cards, 285 cpm
DEC writer II Terminal	30 Characters/Seconds
Interface	Direct Memory Access
I/O Channels	20 Devices
I/O Spare	40 Percent
Available Execution Time	16.6 ms
Required Execution Time	11.5 ms
Spare	31 Percent
Expansion Capability	
Memory	64K 128K Words
Memory Cycle Time	980 Nanoseconds and 300 Nanoseconds
Mass Storage	
Moving Head Discs	44M 320M Words 1.2M 9.6M Words
Tape	1 Drive 8 Drives
Card Reader	285 cpm 1200 cpm
Line Printer	1200 lpm 3000 lpm
I/O	20 Loads 39 Loads

TABLE 4. REAL-TIME CGI SYSTEM

Gaming Area	200 Nautical Mile × 200 Nautical Mile
On-Line Data Base Storage	10,000 Edges and 2000 Point Lights
System Characteristics Lighting Conditions	Daylight, Dusk, Dark
Processed Edges	2000 Edges
Potentially Visible Edges	1000 Edges
Variable Size Light Sources	2000
Directional Lights	Yes
Scene Update Rate	30 Hz or 60 Hz
Calculated Video	499, 784, 973 Lines 524, 823, 1021 Elements/Line
Resolution	524, 823, 1021 Lines Horizontal 374, 588, 729 Lines Vertical
Levels of Detail	8
Moving Models (30 or 60 Hz Update)	8
Total Objects per Scene	256 Objects
Maximum Edge Crossings/Raster Line-System-Commensurate with Video	500, 300, 250 Edge Crossings
Curved Surface Shading	Yes
Digital Edge Smoothing	Yes
Variable Fog/Fading	Yes
Aerial Perspective	Yes
Moving Clouds (Penetration and Breakout)	Yes
Gray Shades (Color Hues with Expanded System)	
—Lights	16
—Models	64
Gray Shade Resolution	256:1
Available Hues	16×10^6
Channels—Implemented	2
—Growth	5
Field of View (Horizontal and Vertical)	Each Channel Independently Variable
Computer Aided Diagnostics	Yes
Built-in Test Hardware	Unified Data Bus

display facilities for these types of experiments. Later phases will use the CGI as the image source for the area-of-interest projector for pilot evaluation experiments. A second series of experiments similar to those performed using the model board system are planned after the initial evaluation is completed. Access to the CGI system for experiments in environment generation is thus assured during the early period after installation.

Modifications and Improvements

A group of modifications and improvements to the image generator hardware have recently been incorporated into the CGI system contract. The changes can be subdivided into increased image generator capability and provisions for future expansion by field modification.

Image Generator Improvements (Added Capability)

1. Two viewpoint capability - the ability to partition the two channels between two completely separate viewpoint definitions can now be accomplished. Before this modification was incorporated, both channels could be assigned to a single viewpoint only. Applications such as air-to-air combat, LSO training, or FLIR simulation can be implemented using two independent viewpoints.

2. Face level of detail processing - the original level of detail implementation provided level of detail changes on a model basis. This caused unnecessary overloading of edge smoothing processing because multiple face edges often intersected the same line element since model level of detail only changed when the model approached element size. The new implementation performs level of detail processing on a face by face basis and faces are eliminated from processing when the face size approaches an element in size. Improved edge smoothing and edge processing loading should result from this change.

3. Blending - An objectional feature of the original level of detail processing was the sudden appearance of models and objects which transitioned into or out of a visible level of detail. The new implementation provides for a gradual blending of the color or intensity of faces toward a background color as they grow, or become small and appear or become eliminated by the level of detail processing.

4. Collision Detection - This change allows the viewpoint to be defined with size and shape of the viewpoint vehicle. These pseudo faces are then tested for intersections with all faces in the data base to determine intersections by the hidden surface logic. When intersections are detected, an interrupt to the general purpose computer is activated.

5. Active Face List Expansion - Experience with the GE Boeing system demonstrated that dusk and low light level environments experienced limitations by the 512 active faces allowed during any display cycle. Point lights are assigned with a limitation of 32 point lights per face. Environments containing high light densities coupled with visible faces encountered overloads in this area. The new implementation provides an additional 512 active faces to be exclusively assigned to point lights.

6. Expanded Point Light Controls - This change provides more flexibility in use of point lights in daylight texture patterns. The modification adds two major functions for control of point lights. Size limit programmability and selection of a rate of change in size curve may be assigned to each light.

7. Mach Band Minimization - Additional precision is included in the fog and fading calculations to minimize the mach band effect under low visibility and low light level conditions.

8. Increased Number of Intensity Levels - The number of gray shades for faces was increased from 64 to 256 and point light intensities from 16 to 256. This change will also allow 256 color registers rather than 64 when the system is expanded to color.

9. Distortion Correction - A technique was incorporated for distorting the computed image to reduce the horizontal keystone distortion which occurs in projecting a flat screen image onto a spherical display surface. The correction will be done in a manner to allow dynamic updating of the correction process as a function of the pitch angle of the projector.

Image Generator Expansion Capability

One of the original CGI system's specifications was that space, power capacity, cooling and back plane wiring be incorporated in the real-time system design to allow field modification of the image generator to add color by simple addition of circuit cards. Similar requirements were required of the recent group of modifications pertaining to expansion capability.

1. Doubling of Edge Capacity - Provisions were made for field expansion of the system to double the number of active potentially visible edges from 1000 to 2000 edges.

2. Doubling Number of Point Lights - Provisions were incorporated in the design to double the number of point lights from 2000 to 4000.

3. Increased Scene Coloring - The number of colors available in the system was expanded from 64 to 264 face colors and 16 to 264 point light colors.

Conclusions

Recent image generator modifications have provided the AWAVS CGI system the latest in hardware capability and programming flexibility. Expansion capabilities incorporated into the design will allow a fully expanded system to be developed with minimal cost for use with the AWAVS VTOL system still in planning stages. Advanced characteristics of the expanded system will allow the CGI system to remain current with production systems for some time yet to come.

The AWAVS CGI System will provide a research capability to investigate real-time CGI image generation technology, on-line and off-line data base programming, environment modeling techniques, simulation of new hardware architectures, and non-real-time image recording techniques. Probably the most significant characteristic of the system will be its availability for data base and environment modeling experiments. The ease of access for environment modification provided by both on-line and off-line interactive data base development facilities will make experiments requiring immediate data base changes at the operators console a reality. Problems in environment modeling still remain as the most important single factor in achieving full utilization of current CGI system processing capabilities. Improvements in development of visual environments will provide the realism and visual cues necessary for effective pilot training.

The combination of advanced hardware designs and data base development facilities will provide the AWAVS facility a sound basis for development of an R&D program supporting the requirements of future visual simulation systems.

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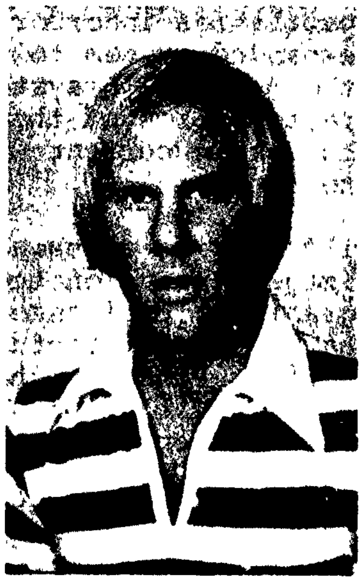
LEVEL-OF-DETAIL CONTROL CONSIDERATIONS
for
CIG Systems



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Robert W. Rife as a Computer Specialist, AFHRL/FTE has been primarily responsible for the CIG on-line software for the ASPT simulator at Williams AFB for the past 1 1/2 years. Previously, he worked with the ASPT advanced training software. He received his B.S. in Computer Science at Purdue University in 1974 and is currently pursuing a Masters Degree in Electrical Engineering at Arizona State University.

LEVEL-OF-DETAIL CONTROL CONSIDERATIONS FOR CIG SYSTEMS

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Computer image generation (CIG) visual systems for flight simulators have various limitations relating to the detail of the visual scene, which can be generated. The Advanced Simulator for Pilot Training (ASPT) system at Williams AFB, Arizona, will be used as this paper's example of a CIG visual system in a discussion of these limitations and techniques used to prevent these limitations (capacities) from being exceeded. Definitions of key words will be followed by a general description of environment pre-selection and a discussion pertaining to edges and edge capacities. The level-of-detail control and the overload algorithm used will be explained, and some general comments pertaining to the problems involved with overload detection will be given.

DEFINITIONS

Edge: Straight line segment defined by two vertices.

Face: A closed convex planar polygon.

2-D Object: A set of non-overlapping coplanar faces.

3-D Object: A set of faces forming a closed convex polyhedron.

2-D Model: A set of 2-D objects.

3-D Model: A set of non-intersecting 3-D objects.

Environment: A collection of models.

Large Model: 3-D's over 400 feet wide; 2-D's over one mile across.

Small Model: 3-D's less than or equal to 400 feet wide; 2-D's less than one mile across.

Viewpoint: The location of the pilot's eyes.

Frame: One-thirtieth (1/30) of a second.

ENVIRONMENT PRESELECTION

The environment is a collection of models, covering an area of 1,250 miles square. Obviously, all models in the environment need not be processed. Three stages of environment preselection exist.

The first stage involves defining two squares (100 mile and 36 mile) around the viewpoint; those large models contained within the large square and small models contained within the small square become candidates for the second stage, while all other models are discarded. When the viewpoint moves to within 15 miles of the small square boundary, the two squares' locations are redefined.

The second stage of environment preselection is the level-of-detail (LOD) processing. The LOD for each candidate is computed, and those models which would be too small on the screen are discarded, leaving the _potentially active models_. The maximum number of LOD candidates is 256, as is the limit for potentially active models. All objects belonging to potentially active models are called _potentially active objects_ (limit is 512).

The third state of environment preselection is performed on the potentially active objects and is called channel assignment or field-of-view (FOV) processing. Those potentially active objects which fall within the defined FOV are called _active objects_ (limit is 256). Any model which contains at least one active object is called an _active model_ (limits are 224 for 2-D models and 100 for 3-D models).

EDGES

The active objects are the end product of environment preselection, and how these active objects produce edges depends on what is meant by "edges." The general definition of an edge in this paper is "a straight line segment between two vertices." In the ASPT system, there are basically four capacities relating to edges.

The first is called the frame 2 edge count (FR2EDGCNT) and is computed by summing the FR2EDGCNT of all active objects; the FR2EDGCNT of an active object is the total number of edges (including hidden edges) of the object multiplied by the number of channels in which the object is displayed. The FR2EDGCNT capacity is 7680.

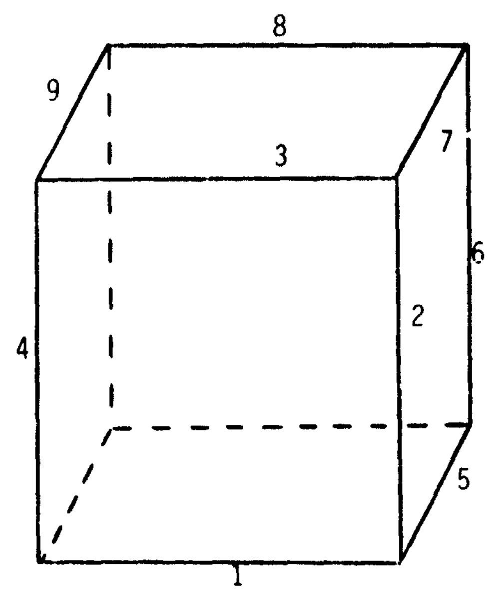
The second edge capacity is the frame 3 edge count (FR3EDGCNT) and is the total number of potentially visible edges. The potentially visible edge capacity of the ASPT system is normally the capacity of most concern, since it dictates how detailed the visual scene can be for a given field-of-view. In most environments created for the ASPT simulator, this limitation (2500 potentially visible edges) has been met or exceeded more often than any other limitations. To compute the FR3EDGCNT, all hidden edges within each object are first eliminated. For a given scene, some objects may be completely

masked or blocked from view by other objects. These objects blocked from view will still have some potentially visible edges, so they will contribute, as if they were visible, to the FR3EDGCNT even though they will not be displayed.

The cube in Figure I, with its given orientation to the viewer, would have nine potentially visible edges, if it did not cross any channel boundaries. If the cube were to cross channel boundaries, then more edges would be exhausted, as in Figure II. A two-dimensional rectangular object will use four potentially visible edges, if it is displayed in only one channel, seven edges if in two channels, and more edges if in more channels.

One example of how the FR3EDGCNT of one object can vary is a 25-sided irregular-shaped object used to represent a town in the ASPT Williams AFB environment. From a distance, with the town in one channel, the FR3EDGCNT is the expected value of 25, but when flying over the town (the object being in many channels simultaneously), the FR3EDGCNT sometimes exceeded 100.

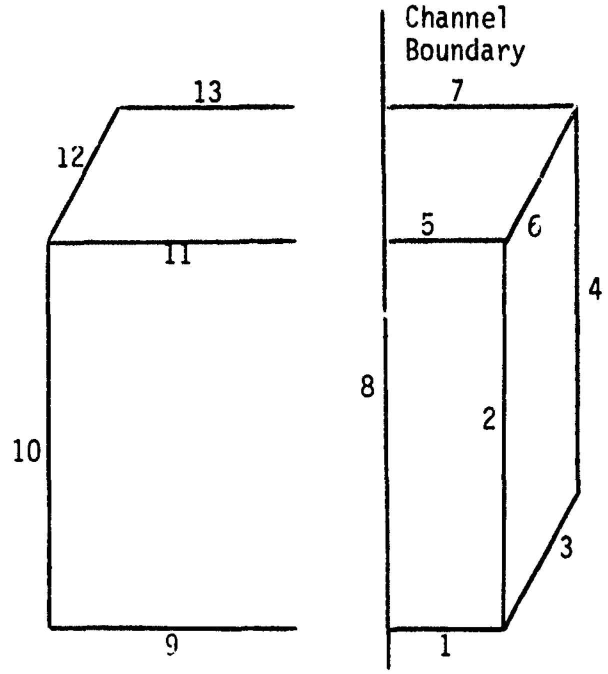
The third and fourth edge capacities are the number of edge crossings per raster line for a given channel (limit is 256), and the number of edge crossings per raster line for the whole system (limit is 1,024). These capacities can be reached, for instance, when a grid or texture pattern is oriented in such a way as to have many edges running approximately perpendicular to the raster lines.



CUBE IN ONE CHANNEL

Nine Potentially Visible Edges

FIGURE I

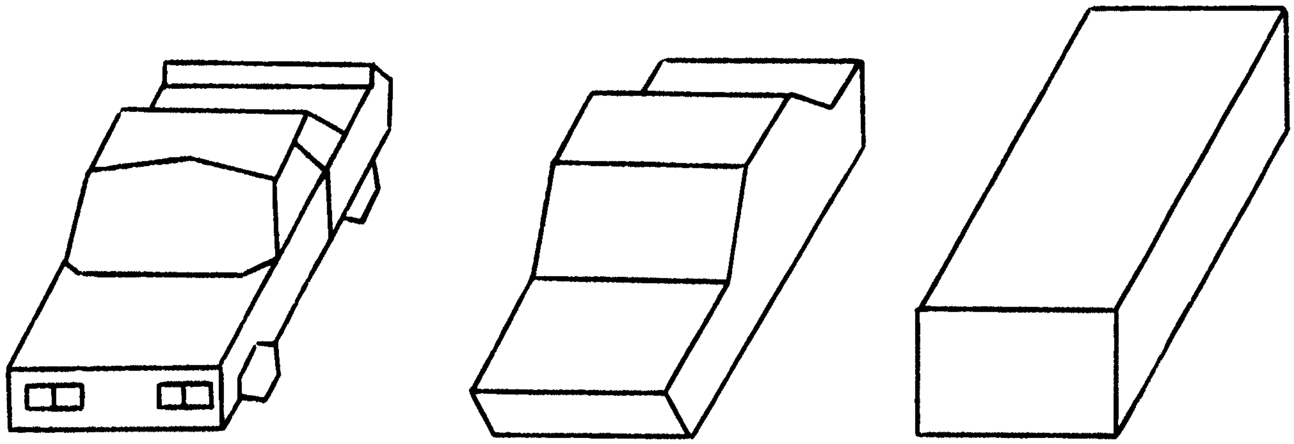


CUBE CROSSING CHANNEL BOUNDARIES

FIGURE II

LEVEL OF DETAIL (LOD) PROCESSING

As stated earlier, the second stage of environment preselection is LOD processing. Here, for each model that is a LOD candidate, the appropriate complexity of the model is selected consistent with its visibility to the pilot. Use of this technique results in the elimination of objects or faces too small to be perceived and reduces the chances of overloading the edge capacities of the special purpose computer. Figure III illustrates this process and shows three different levels of detail for a particular model. The first level might be that processed for viewing from close proximity to about 250-foot distance from the model; the second level might be used from 250 feet to 1,000 feet; and the third level from 1,000 - 4,000 feet. Beyond 4,000 feet, the model would no longer be selected for field-of-view processing.



a. First Level   b. Second Level   c. Third Level

FIGURE III

<table>
<tr><td>X
Location</td><td>Y
Location</td></tr>
<tr><td>Model
Size</td><td>Model
Priority</td></tr>
<tr><td colspan="2">LOD 1
Disc Address</td></tr>
<tr><td>LOD 2
Offset</td><td>LOD 3
Offset</td></tr>
</table>

MODEL LOD INFORMATION BLOCK

FIGURE IV

As Figure III illustrates, the ASPT software allows up to three levels-of-detail for each model with LOD1 being the most detailed and LOD3 being the least detailed. Which LOD a model should be depends, in general, upon how many raster elements the model subtends on the screen. This value is computed for each model as a function of the size of the model and its distance to the viewpoint. The size of the model is computed off-line and is stored as part of the model's LOD information block (Figure IV). The distance between the model and the viewpoint is computed by the special purpose computer's dot-product calculation, using the model's location data in the LOD information block and the altitude and location of the viewpoint.

Two equations are used (one for 2-D models and one for 3-D models) to compute at which LOD a model should be displayed.

(1) $R^2 \leq \left[\frac{Size}{K * N}\right]^2$ for 3-D models

(2) $R^2 \leq \frac{2*Size*ALT}{K * N} + Size^2$ for 2-D models

See the appendix for derivations of these equations.

R^2 = Range squared between viewpoint and model.

Size = Model size.

K = .001924 = tangent of angle subtended by one raster element.

ALT = Altitude of viewpoint.

N = Integer value defining minimum number of raster elements a model must subtend to be displayed at some LOD.

Using the example described earlier (Figure III) and given that N equals 2, 8, and 32 for LOD3, LOD2, and LOD1, respectively, and approximating K with .002, the specified ranges for LOD's of the car model (16-foot size) follow:

$$\frac{Size}{K * N} = \frac{16 \text{ ft}}{.064} = 250 \text{ ft for } N = 32 \text{ (LOD1)}$$

$$\frac{Size}{K * N} = \frac{16 \text{ ft}}{.016} = 1000 \text{ ft for } N = 8 \text{ (LOD2)}$$

$$\frac{Size}{K * N} = \frac{16 \text{ ft}}{.004} = 4000 \text{ ft for } N = 2 \text{ (LOD3)}$$

For 2-D models, the equation used is similar to that of 3-D models, except the altitude of the viewpoint is given weight. The level-of-detail of a runway would tend to be higher for a given range, if the viewpoint altitude were higher, which is consistent with "real-world" situations.

These values computed for each model which are compared to the viewpoint's range to each model and define the three LOD thresholds are constants for 3-D models and constants multiplied by the viewpoint altitude for 2-D models. However, if a model, object or edge capacity of the system is being approached, these LOD threshold values must be adjusted to effectively increase the number of raster elements subtended for a given LOD of a model. Thus, the level-of-detail of the visual scene will be reduced, and the overload problem will be prevented or corrected.

EDGE OVERLOAD

Edge overload exists when any of the edge capacities of the system are exceeded and results in distracting streaks and/or "flashing" of the visual scene. The ASPT hardware will generate the edges for Channel 1, Channel 2, ...Channel 7 in sequence and may, for example, exhaust the potentially visible edges during one frame halfway through Channel 5, leaving part of Channel 5 and all of Channels 6 and 7 blank. The next frame this FR3EDGCNT may overload halfway through Channel 6 as the aircraft (viewpoint) orientation changes, thus the flashing scene. Streaks will occur in the display, if the edge-crossing-per-raster-line limit is exceeded. In any case, edge overload results in a very distracting and certainly undesirable degradation of the visual scene.

The prevention and cure of edge overload is attempted in the LOD processing stage of environment preselection by adjusting, when needed, the LOD threshold values and thus reducing the level-of-detail (edge requirements) of the visual scene. If this adjustment is done similarly for all models without any prioritization scheme, then some models which are in front of the pilot may change LOD before some models on the sides change LOD, which would be more distracting than if the opposite were true. Also, some models might be critical to the pilot (targets, for example) and may change LOD or be deleted.

The current ASPT overload algorithm is designed with these two problems in mind. Models are prioritized in two ways: (1) Model importance, and (2) Channel prioritization. Models are given one of three priorities off-line: (1) Critical, (2) Important, and (3) Standard. All models are prioritized on-line, depending on whether they are in designated high priority channels or low priority channels.

Equation 1 shows how the LOD threshold values are computed for 3-D models. Actually, the equation is:

$$(3) \quad R^2 \leq ALPHA^J \left[\frac{Size}{K * N}\right]^2 \quad \text{where } J = 0, 1, 2, 3,\ldots \quad 0 < ALPHA < 1$$

Normally, J equals zero, so equation (3) is equivalent to Equation 1. However, when overload is present or approaching, J is incremented, thus reducing the value of the right side of the equation. Consequently, the number of raster elements that a model must subtend on the screen for a given LOD increases, or, equivalently, the threshold range for a given LOD decreases.

Table I indicates the sequence followed in adjusting the LOD threshold values. The first pass after detecting an overload condition, the LOD threshold values for all standard models in low priority channels will be adjusted by incrementing J to 1 for these models. Some models may need to change LOD on this pass (some perhaps due to the adjustment). After all models that were to change LOD on this pass have been changed, then another adjustment pass can occur, if the overload condition is still present. On the second pass, J will be incremented to 1 for standard models in high-priority channels as well. If this adjustment still does not solve the overload problem, more adjustment passes will be taken until the problem is solved. Notice that critical models' LOD threshold values are never adjusted, so they should be used sparingly. Once a stable state is reached with the overload eliminated, the values of J for the various model prioritizations will remain unchanged until either overload or underload occurs, causing J values to be again incremented or decremented, respectively. A hysteresis effect is included in the algorithm to prevent repeated changes of LOD near a threshold condition. This is accomplished by requiring a few seconds after an LOD change, before another LOD change for the same model is allowed.

The magnitude of the adjustment of LOD threshold values is regulated by both ALPHA and J, so these variables should have values which will prevent overload from occurring or at least correct the condition rapidly, if it does occur. The values chosen for ALPHA should depend on the severity of the overload problem and the speed with which LOD's of models can be changed. To detect an approaching overload problem or judge its severity and then correct the problem is not a simple task. There is, to the author's knowledge, no scheme which will work adequately for all environments or situations. The ASPT software monitors the FR2EDGCNT and FR3EDGCNT, as well as other counts (object, model, edge crossings per raster line, etc.) that are relevant and uses a simple scheme to judge overload.

Recall that the FR3EDGCNT capacity is 2,500 potentially visible edges. When the FR3EDGCNT reaches 2,000 or 80% capacity, the overload condition is met, and the LOD threshold adjustments begin. The adjustment passes continue

CR = Critical model

IH = Important model in high-priority channel

IL = Important model in low-priority channel

SH = Standard model in high-priority channel

SL = Standard model in low-priority chanel

SL(J) = Exponent of ALPHA for standard models in low-priority channels

ADJUSTMENT PASS	SL(J)	SH(J)	IL(J)	IH(J)	CR(J)
1	1	0	0	0	0
2	1	1	0	0	0
3	1	1	1	0	0
4	2	1	1	0	0
5	2	2	1	0	0
6	2	2	2	0	0
7	2	2	2	1	0
8	3	2	2	1	0
9	3	3	2	1	0
10	3	3	3	1	0
11	3	3	3	2	0
12	4	3	3	2	0

TABLE I

until the FR3EDGCNT drops below 2,000 (overload condition eliminated). If the FR3EDGCNT drops below 1,625 or 65%, then underload exists, and the adjustment sequence reverses itself until underload is eliminated. Consequently, the algorithm attempts to hold the FR3EDGCNT between 65% - 80% capacity bandwidth. This bandwidth can be raised, lowered, widened or narrowed. If the bandwidth is too narrow, then the system may oscillate between overload and underload and cause a distracting blinking of models in and out of the display. If the bandwidth is too high, overload may not be detected soon enough to prevent the true hardware edge overload (streaking, flashing) from occurring. The worst case in the ASPT system is caused by flying straight-and-level over a dense environment with a FR3EDGCNT at 1950, for example, and then suddenly rolling to the left. This action changes the orientation of the aircraft in such a way as to make many more active objects out of what were only potentially active objects (FOV processing) before the roll. The FR3EDGCNT can skyrocket to 2500-3000 edges in a fraction of a second, and true hardware edge overload occurs. The overload algorithm cannot react quickly enough, partly because the overload detection scheme is perhaps too simple, but primarily because of computer and peripheral limitations.

A more complicated scheme of overload detection or anticipation will probably involve monitoring some combination of capacity parameters and weighting these parameters in some fashion based on experimental data. The ASPT system is just now acquiring the capability to record in real-time all the parameters relevant to overload, and work will be done to improve its overload detection algorithm by analyzing the recordings. However, regardless of how sophisticated the detection scheme is, the primary problem will still exist.

The ASPT system can change the LOD of only one model per frame, so in worst cases, hardware overload may not be prevented. Recall that if an adjustment pass is made to adjust the LOD threshold values, and five models, for example, need to change LOD on that pass, it would take five frames (minimum) to change the LOD of all five models. After this was done, another adjustment could be made, if needed. If the overload condition is examined every frame with adjustments made every frame (not waiting until all models related to a certain adjustment pass have changed), then an overrun condition is likely to occur, probably causing too many models to be deleted or changed to lower LOD's and causing underload.

Ideally, all models that need to change LOD on a given adjustment pass should be changed on that pass (frame). This would require either much faster hardware or much more memory to store all three LOD's of models in the special purpose computer simultaneously.

If this were the case, then the aircraft roll described above would probably not cause true edge overload, since enough models could be changed to lower levels-of-detail fast enough to prevent it.

In summary, level-of-detail control and overload prevention is not a trivial problem in the ASPT system. An inadequate overload algorithm can cause as many distracting problems as it corrects, and designing an algorithm which will perform satisfactorily for all situations will take more investigating and analysis of all related parameters. The author feels that such analysis is worthwhile, because regardless of the capacity of future systems, we will design and model environments which will turn on that red overload light.

APPENDIX

The following derivations are excerpts from a General Electric preliminary investigation release (PIR) written by William A. Kelly in June 1973. At that time the ASPT simulator was called ASUPT.

Basically, the test for level-of-detail is based on a comparison of range squared to a constant for each model to determine if that model subtends a specified number of elements on the screen. The changing of level-of-detail is then done when each model subtends more than some number of elements. These specific number of elements will not be determined until ASUPT is operational.

As background, the derivation of the testing algorithm will be shown here, using the system constants from ASUPT.

<u>Derivation</u>:

Solve for the tangent of the angle subtended by one element.

w	=	width of one element	(1)
d	=	half width of the screen	(2)
J_M	=	elements per raster line	(3)
γ_o	=	angle subtended by one element	(4)
P	=	distance viewpoint to screen	(5)
β	=	angle subtended by half screen with overscan	(6)

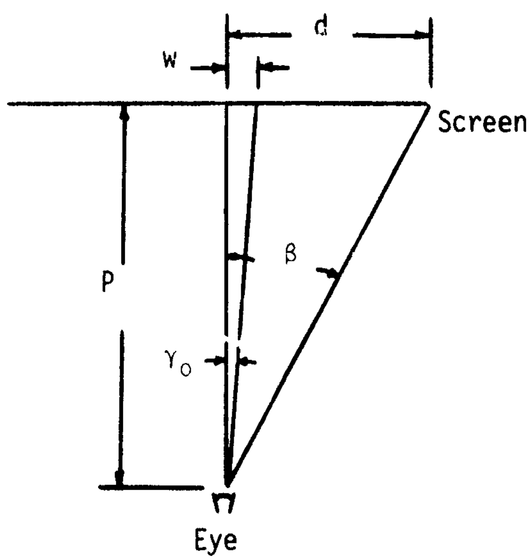


Figure A

From Figure A

Width of one element

$$w = {}^{2d}/_{J_M} \tag{7}$$

$$\tan \gamma_o = w/P \tag{8}$$

$$\tan \beta = d/P \tag{9}$$

$$d = P \tan \beta \tag{10}$$

Substituting (7) and (10) into (8) yields

$$\tan \gamma_o = \frac{{}^{2d}/_{J_M}}{P} = \frac{{}^{2(P \tan \beta)}/_{J_M}}{P} \tag{11}$$

$$\tan \gamma_o = \frac{2 \tan \beta}{J_M} \tag{12}$$

In expression (12), each term on the right side is a system constant and for ASUPT

$$\beta = 44^{o}34' \tag{13}$$

$$J_M = 1024 \tag{14}$$

Therefore:

$$\tan \gamma_o = \frac{2(\tan(44^{o}34'))}{1024} \tag{15}$$

$$= .001924$$

Let R_B = radius of ball enclosing model

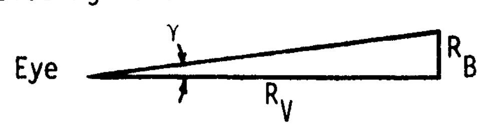


Figure B

$$\tan \gamma = {}^{R_B}/_{R_V} \tag{16}$$

If the tan γ is greater than tan γ_o, the model subtends more than one element on the screen.

Test:

$$\tan \gamma_o \leq \tan \gamma = {}^{R_B}/_{R_V} \tag{17}$$

$$\text{where } R_V^{\,2} = x^2 + y^2 + z^2 \tag{18}$$

or:

$$R_V \leq \frac{R_B}{\tan \gamma_o} \tag{19}$$

or:

$$R_V^{\,2} \leq \left[\frac{R_B}{\tan \gamma_o}\right]^2 \tag{20}$$

The right side of expression (20) is constant per model as a function of R_B, its critical radius, and tan γ_o, a system constant. Test (20) will determine if the model radius subtends one element on the view screen. For other levels of detail, the number of elements the model subtends is again a constant (to be established on ASUPT).

Assumption: For N elements subtended

$$\tan N \gamma_o = N \tan \gamma_o \tag{21}$$

so that in general the level of detail test for changing levels is

$$R_V^{\,2} \leq \left[\frac{R_B}{N_i \tan \gamma_o}\right]^2 = \frac{1}{N_i^{\,2}} \left[\frac{R_B}{\tan \gamma_o}\right]^2 \tag{22}$$

N_i = elements subtended for level i.

<u>Surface 2-D Test</u>

For surface models, 2-D, the test should be modified to account for the altitude of the viewpoint above the surface plane. As the altitude decreases, the number of elements subtended by the model decrease, even though the model may be very large.

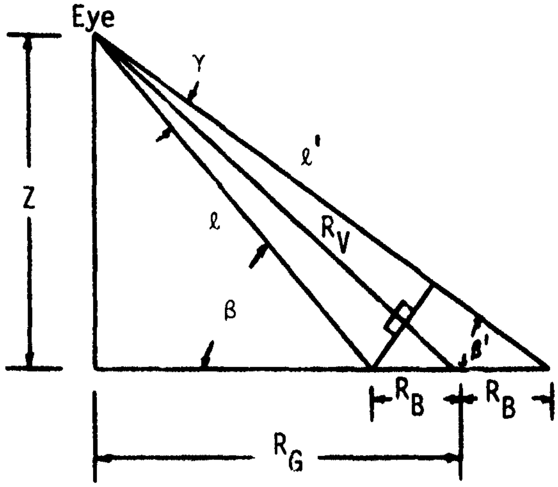


Figure C

Law of sines:

$$\frac{\sin \gamma}{2\ R_B} = \frac{\sin(180-\beta)}{\ell'} \tag{25}$$

Using $\sin(180-\beta) = \sin \beta$

$$\sin \gamma = \frac{2R_B \sin \beta}{\ell'} \tag{26}$$

Law of cosines:

$$\cos \gamma = \frac{\ell^2 + \ell'^2 - (2R_B)^2}{2\ell\ell'} \tag{27}$$

Define γ - angle subtends projected diameter of ball

$$\tan \gamma = \frac{\sin \gamma}{\cos \gamma} = \frac{2R_B \sin\beta/_{\ell'}}{(\ell^2 + \ell'^2 - 4R_B^2)/2\ell\ell'} \tag{28}$$

$$= \frac{4R_B \ell \sin\beta}{\ell^2 + \ell'^2 - 4R_B^2} \tag{29}$$

$$\ell^2 = Z^2 + (R_G - R_B)^2 = Z^2 + R_G^2 - 2R_GR_B + R_B^2 \qquad (30)$$

$$\ell'^2 = Z^2 + (R_G + R_B)^2 = Z^2 + R_G^2 + 2R_GR_B + R_B^2 \qquad (31)$$

Substitute:

$$\tan\gamma = \frac{4R_B\ell\sin\beta}{2Z^2 + 2R_G^2 + 2R_B^2 - 4R_B^2} \qquad (32)$$

$$= \frac{2R_B\ell\sin\beta}{Z^2 + R_G^2 - R_B^2} \qquad (33)$$

using $\sin\beta = Z/\ell$

$$\tan\gamma = \frac{2R_BZ}{Z^2 + R_G^2 - R_B^2} \qquad (34)$$

using $Z^2 + R_G^2 = R_V^2$

define $\tan\gamma_0$ minimum angle

$$R_V^2 - R_B^2 \le \frac{2R_BZ}{\tan\gamma_0} \qquad (35)$$

$$R_V^2 \le \frac{2R_BZ}{N_i\tan\gamma_0} + R_B^2 \qquad (36)$$

The test (36) now consists of a multiply and a constant add per model as opposed to the previous test (23). The angle (γ) is now defined as the angle which subtends a diameter, rather than a radius of the ball around the model, still a constant.

A FAST, FLEXIBLE MODEL TO SIMULATE AIR FRAME DYNAMIC RESPONSE CHARACTERISTICS

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A FAST, FLEXIBLE MODEL TO SIMULATE AIR FRAME DYNAMIC RESPONSE CHARACTERISTICS

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ABSTRACT

This paper describes a flexible, user-oriented simulation model comprised of selectable linear digital transfer functions that relate control inputs to air frame dynamic response variables. These transfer functions can be specified by the user to relate any input to any response variable, thereby enabling the simulation of any desired degree of dynamic cross coupling.

1. INTRODUCTION

A new dynamic model was developed by the author for use in man-in-the-loop aircraft simulators. The model, which provides a simplified digital program for real-time simulation of aircraft dynamic response characteristics, digital computer program consisting of user-selectable linear digital transfer functions that relate pilot control inputs to airframe response variables.

This model was developed and used in the System Simulation Laboratory at IBM Owego to support several aircraft simulation exercises. It was born from the need of creating a realistic airborne environment for experienced pilots or operators to "fly" while experiments in weapon delivery techniques, display evaluation, or software validation were being conducted. That need dictated low processing overhead within the simulation computer and inherent versatility of the algorithms, to successfully simulate the flying characteristics of several different high performance aircraft. Although standard six-degree-of-freedom software packages were available for this use, the requirements of rapid execution and easy personalization could not be satisfied conveniently. Hence the model was developed from the alternative perspective of capsulizing an aircraft's handling qualities with representative transfer functions, to relate airframe behavior to pilot control inputs. Personalizing the model's performance of typify that of any specific aircraft is a simple matter of trial-and-error adjustments of certain processing gains to align simulated airframe response to a pilot's experience. This tuning procedure has proved to be rather easy in past exercises, and good initial guesses of parameter values are easily derived from off-line analysis without having to acquire a substantial data base.

2. GENERAL

A pivotal element of an aircraft flight simulator is the mathematical model by which the rotational dynamic response characteristics of the aircraft-autopilot loop are simulated. For simulators using real-time digital computers, a typical approach involves the real-time solution, by numerical integration techniques, of a complex, highly interactive set of differential equations that characterize those dynamic responses. The coefficients of the equations are, in general, functions of aircraft aerodynamic stability derivatives, inertia characteristics, aircraft flight conditions, and autopilot characteristics.

This approach just outlined generally has several drawbacks, as summarized below:

- The formulation of the mathematical dynamic model requires detailed and quantitative knowledge of the aircraft aerodynamic coefficients and stability derivatives and also an adequate autopilot dynamic model. That kind of detailed information is typically hard to acquire. The required data may, in fact, exist but be considered proprietary; thus, unavailable.

- Even if the necessary data exist, it is not unusual for the corresponding mathematical model to become quite complex, involving many terms, some of which may be parasitic or negligible in their contribution to overall system dynamics. In an attempt to simplify the model, the problem often hinges upon which terms can be safely neglected. If all terms are retained, the program may exceed the processing capacity of the object machine. That, of course, depends on model complexity, the numerical integration algorithm, integration step size, ancillary per-cycle data processing, input/output loading, and processor execution speed.

- Probably the toughest problem relating to the above approach is developing an adequate numerical integration algorithm, or method, to solve the dynamic model in real time and achieve the desired (modeled) dynamic response characteristics. Any digital implementation is, in effect, a sampled data representation of a continuous system and, as such, is afflicted with all the associated problems, stability being perhaps the most difficult.

- The traditional approach normally requires either seven or nine numerical integrations per computation cycle to solve the rotational dynamics and direction cosine matrix update, depending upon whether quarternions (seven integrations) or direction cosine derivatives (nine integrations) are used, as shown below:

Integration Variable	Transformation Update Method Direction Cosine	Quarternion
Angular acceleration	3	3
Direction cosine time derivation	6	NA
Quarternion time derivative	NA	4
Total Integrations	9	7

The new model represents a radical departure from the traditional method just described. It constitutes a simpler approach to the implementation of the airframe dynamics problem, and depends on user-specified transfer functions and corresponding steady-state gain coefficients. Those are used to transform airframe control inputs (stick, rudder, and throttle deflections) into airframe dynamic response variables. Digital transfer functions can be specified by the user to relate any input to its corresponding output. The rotational equations and associated fixed-to-body frame direction cosine matrix requires only one numerical integration per calculation cycle (that is integration of roll rate), as contrasted with the seven or nine generally required for the traditional approach.

The new model and the conventional method for simulating aircraft dynamics are compared in Table 1.

3. ASSUMPTIONS

The following were assumed in developing the new dynamic model:

- The earth is flat, nonrotating, and has a constant gravity vector.
- The airframe behaves as a rigid body.
- Required aircraft response can be modeled by linear transfer functions.
- Aerodynamic drag acts only along the roll axis and is a function of dynamic pressure (Q), control surface deflections, and corresponding user-specified drag coefficients.

- Accelerations induced by control deflections are proportional to Q and deflection amplitude.

- All reference frames are right-handed and orthogonal.

4. SIMULATION FUNCTIONAL DESCRIPTION

A generalized aircraft man-in-the-loop simulation functional block diagram is provided on Figure 1.

The simulation is comprised of the following functional elements (See Figure 2).

Real World Image System

Provides a pictorial representation of the pilots 'out-the-window-view in response to pilot induced control inputs.

Cockpit

Comprised of flight instruments driven by corresponding real-time software models and engine and airframe controls which provide inputs to 'Realtime Equations of Motion' software, described below.

Interface Equipment

Provides interface between simulation hardware (i.e., 'Real World Image System, Instruments, and Controls) and Simulation Software.

Computer/Program

Transforms control inputs into outputs which drive the 'Real World' Image System and cockpit instruments via real time, iterative numerical solution of:

a. The 'Equations of Motion' software which transforms control inputs into airframe kinematic parameters (i.e., position, velocity, and body attitude variables as shown in Figure 3) and

b. The 'Instrument' and 'Image System' software which transforms the airframe kinematic parameters into signals which drive the 'Real World Image System' and Cockpit Instruments.

Equations of Motion Software

The Equations of Motion Software is sequenced as follows:

Atmospheric Model - transforms airframe altitude and speed into pressure altitude and dynamic pressure, 'q'.

Translational Equations - transforms applied control and aerodynamic forces into three components of linear acceleration which are transformed from body axes to earth axes and combined with gravity acceleration, from which velocity and position are generated via a total of six (6) real time integrations (three (3) to generate velocity from acceleration and three (3) to generate position from velocity).

The conventional method (See Figure 4) generates applied aerodynamic force as a function of dynamic pressure, pitch and yaw angles of attack in conjunction with (typically) a complex aerodynamic equation set which requires (typically) a correspondingly large number of aerodynamic coefficients. Control forces are (typically) generated by another (typically) complex set of equations to simulate required autopilot dynamics in conjunction with still more aerodynamic coefficients.

In contrast to the conventional method, the new method (See Figure 5) transforms control inputs into linear acceleration via a set of user-specified gain coefficients thus eliminating the requirement for either a complex aerodynamic or autopilot model.

Rotational Equations - The conventional method of implementing the rotational equations (See Figure 6) is to first compute the net applied aerodynamic and control moment (generated, again, by typically complex aerodynamic and autopilot equations) which is multiplied by the inertia tensor to develop three components of angular acceleration, $\dot{p}$, $\dot{q}$, $\dot{r}$, as shown on Figure 7. These are each integrated once to generate angular rate components (p, q, r) from which the body axes to earth axes coordinate transformation derivatives are first computed and then integrated to generate the required transformation.

A total of either nine (9) or seven (7) realtime numerical integrations are required to generate the transformation, depending upon whether direction cosines (9) or quaternions (7) are used.

In contrast to the conventional method, which requires multiple realtime numerical integrations to generate the transformation, the new method requires the realtime numerical integration of only one variable (See Figure 8). The body axes to earth axes transformation elements are generated as closed form. algebraic expressions (as contrasted by realtime numerical integrations) of body attitude parameters. These parameters are generated by user-specified, linear digital transfer functions which relate control inputs to the airframe rotational dynamic response variables.

Any desired degree of cross coupling can be simulated by selective specification of non-zero values for cross-coupling coefficients in the rotational dynamic response model.

The 'tuning' process by which the model can be experimentally modified to align the dynamic response to a pilots experience, involves 'tweaking' these coefficients between successive simulation runs. Experience has demonstrated that Un's process to converge rapidly to produce the desired 'handling' characteristics.

Instrument and Real World Image System Equations

Transforms airframe position and attitude variables into drive signals for Cockpit Instruments and Real World Image System.

COMPARISON

Significant characteristics between the new and conventional method for simulating airframe dynamic response are summarized in Table 2.

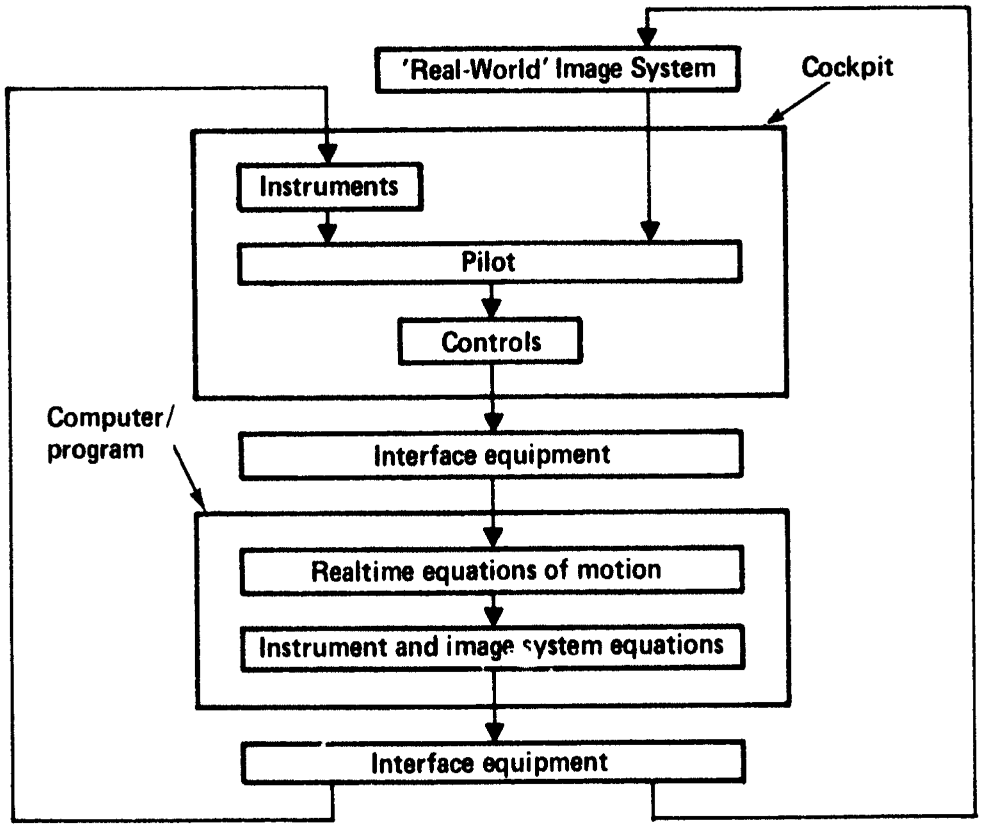

Figure 1. Generalized Aircraft Man-In-The-Loop Simulation Functional Block Diagram

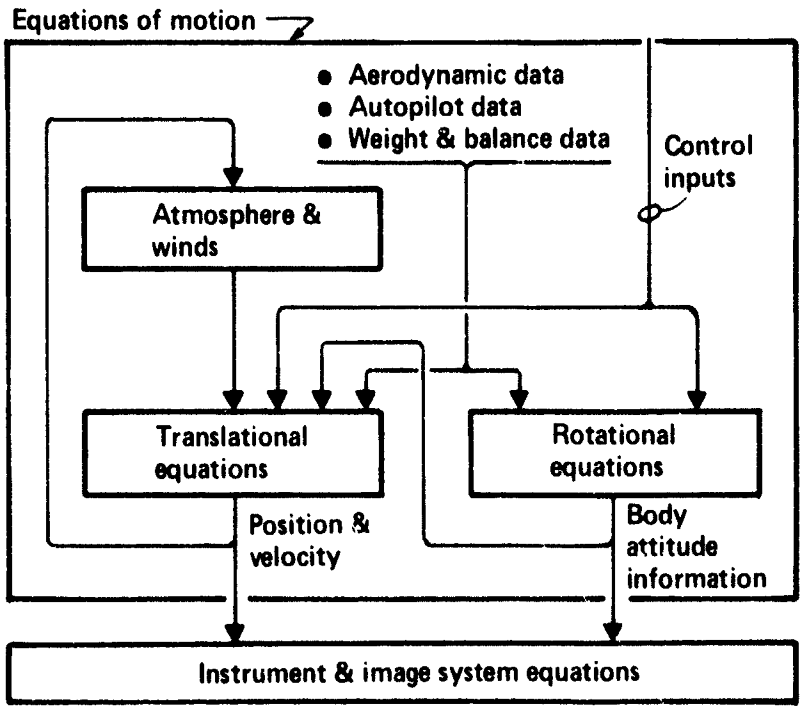

Figure 2 Equations of Motion Functional Partitioning

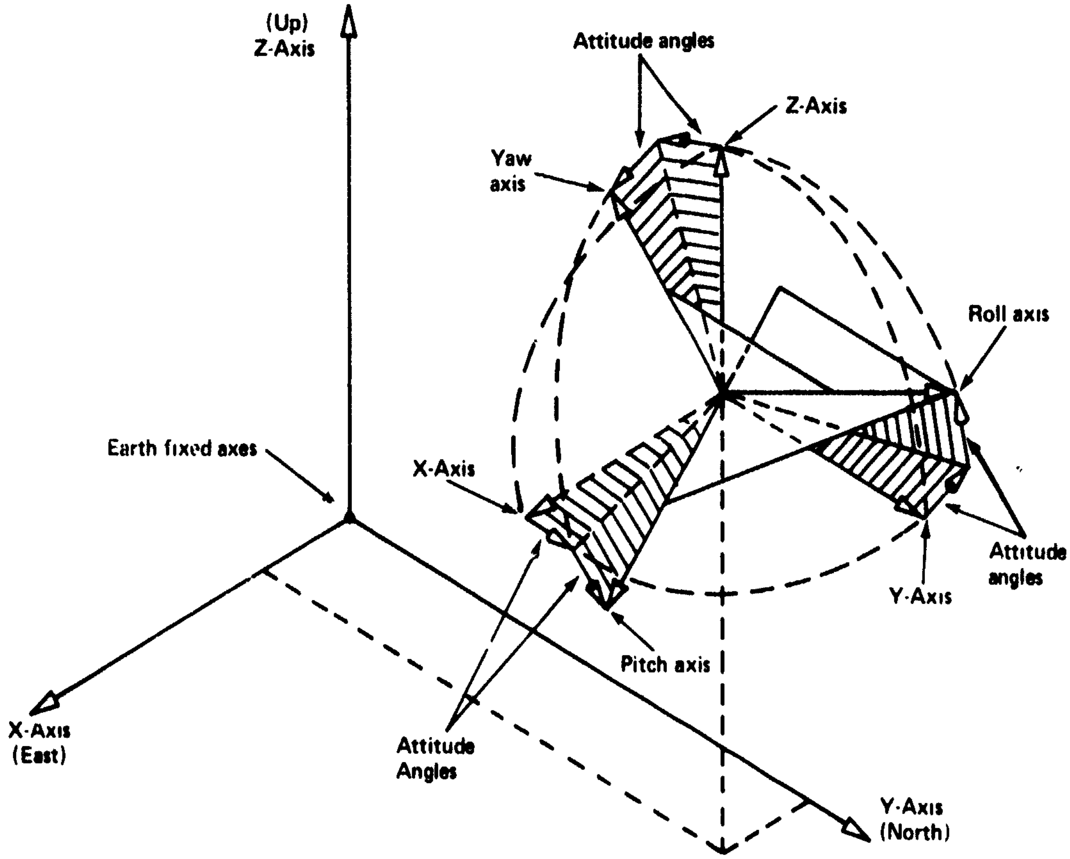

Figure 3. System Geometry

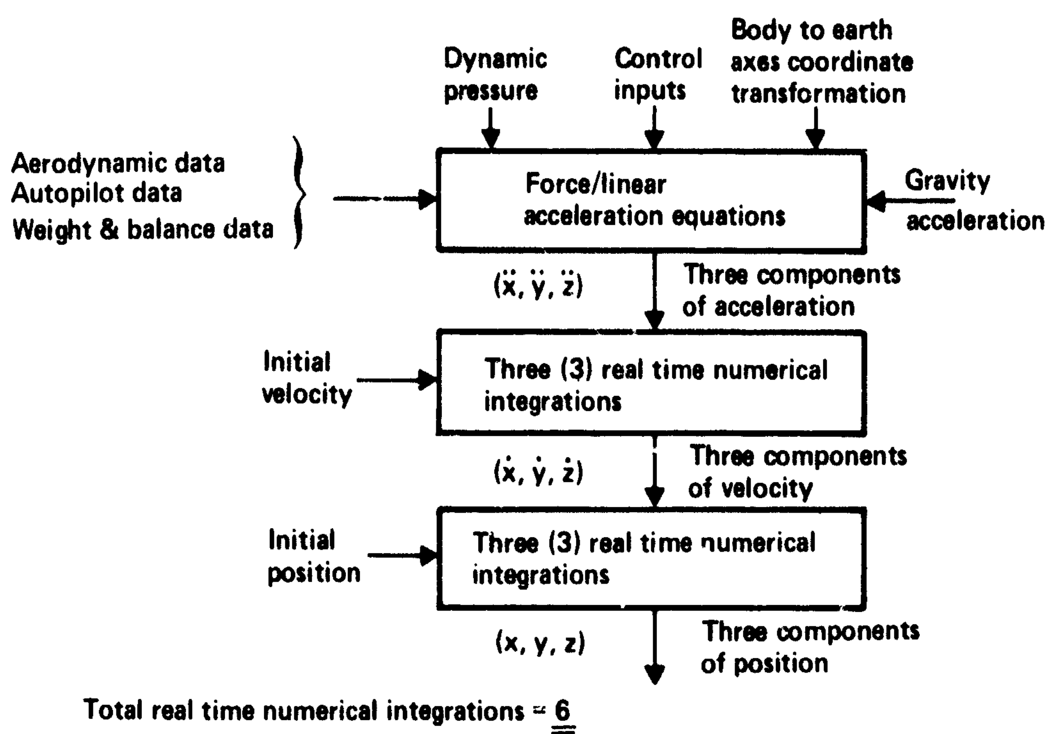

Figure 4. Conventional Translational Equations Summary

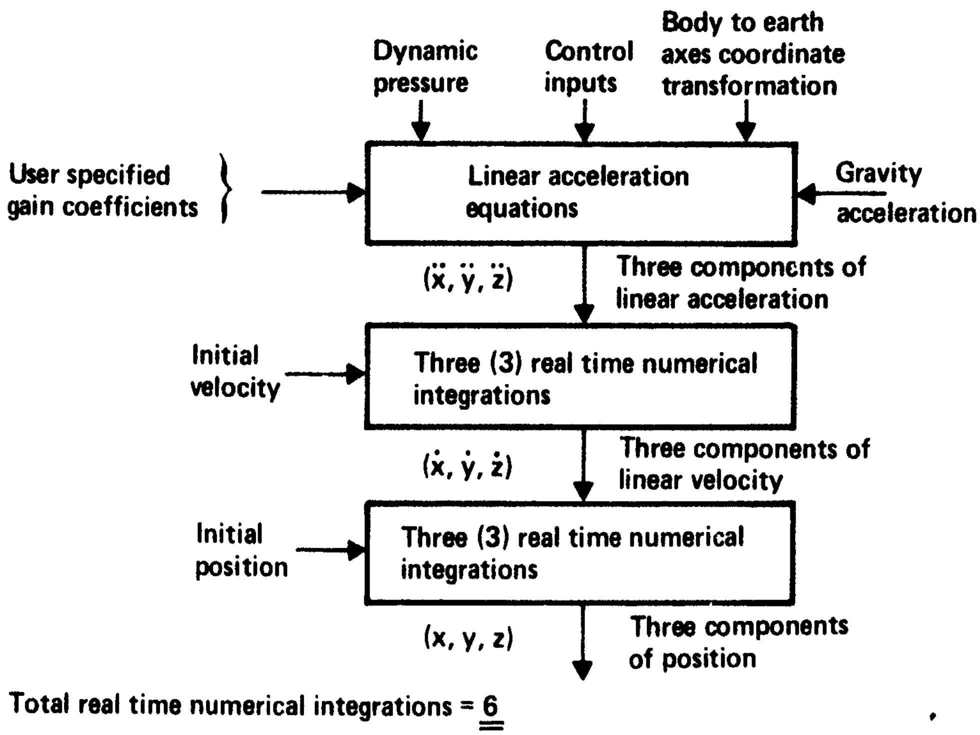

Figure 5. New Method Translational Equations Summary

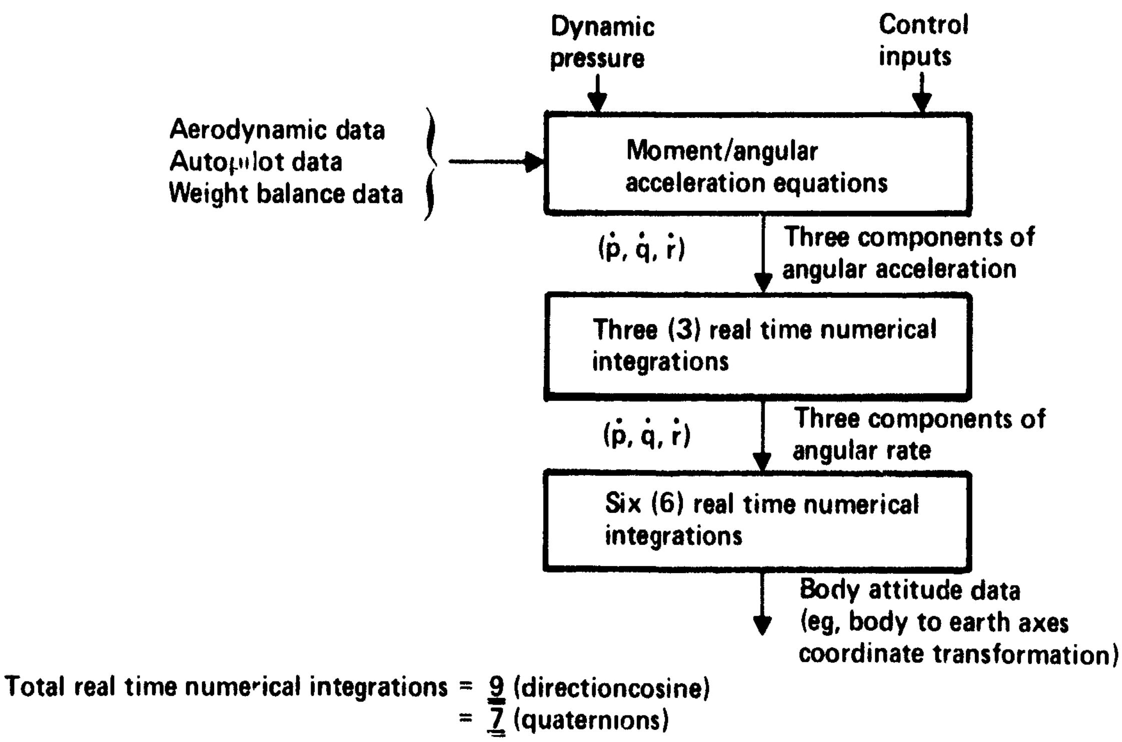

Figure 6. Conventional Rotational Equations Summary

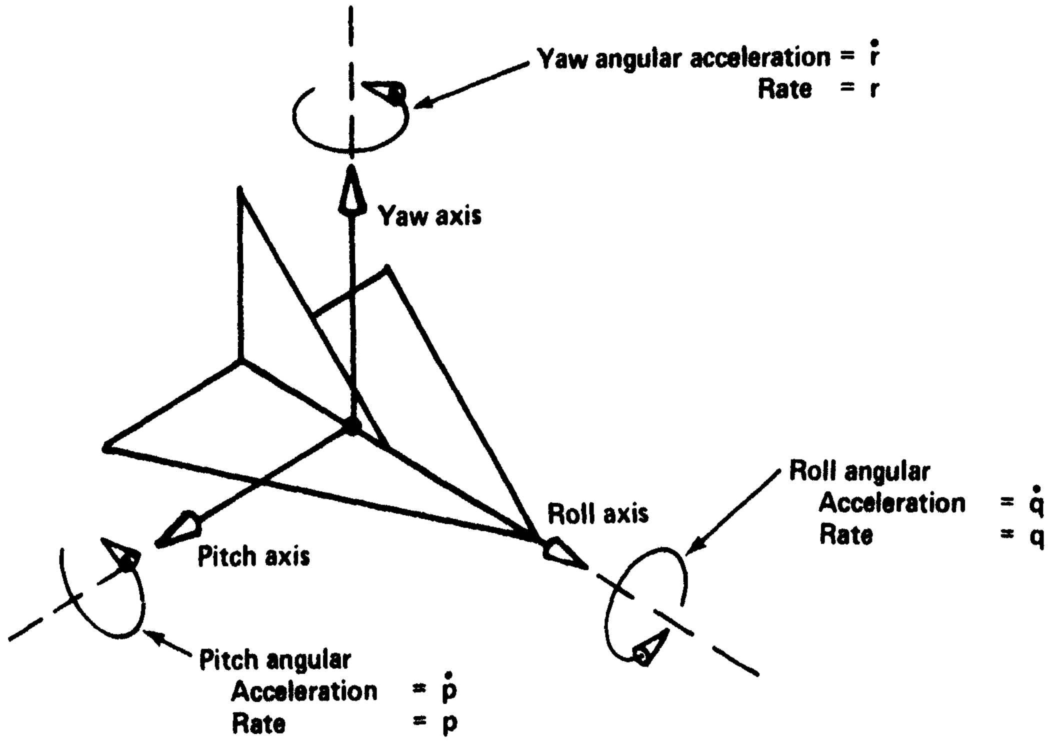

Figure 7. Angular Kinematic Parameters
(Not required for New Model)

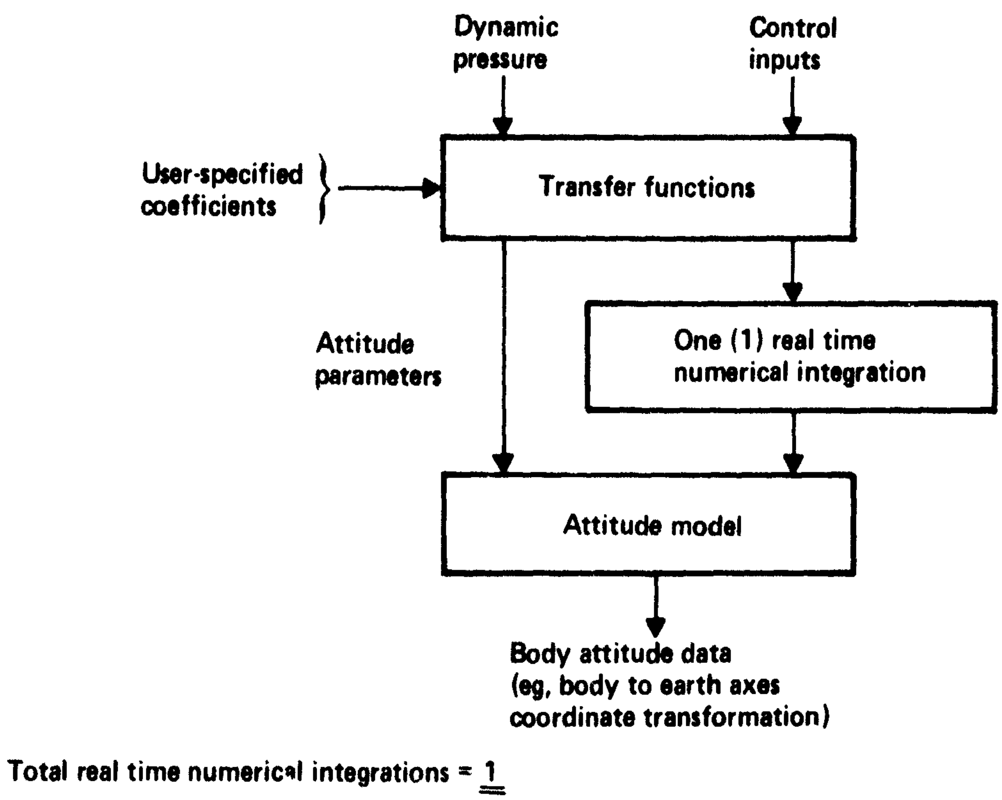

Figure 8. New Method-Rotational Equations Summary

Table 1. Comparison of New Dynamic Model and Conventional Aircraft Dynamic Response Model

Characteristic	New Dynamic Model	Conventional Dynamic Model
Model type	User-specified digital transfer functions relate stick, rudder, and throttle inputs to aircraft acceleration and rotational response.	Interactive algebraic and differential equations
Form of data	Transfer function steady-state gains, dynamic parameters. May require intermediate analysis (root locus, for example) of analytical model to determine transfer function poles and zeros.	Aerodynamic stability derivatives, air frame weight, balance, inertia, autopilot parameters
Ability to simulate desired dynamic response characteristics	Excellent	Closed-loop sampled data effects make specified dynamic response characteristics typically hard to achieve. May be difficult (if not impossible) even using digital compensation methods.
Equation Stability	Excellent	Typically fair to poor
Number of numerical integrations per computation cycle for rotational dynamics	One	Seven or nine, depending on direction cosine update method
Flexibility, ease of changing dynamic models	Excellent	Typically fair to poor, depending on degree of difference between new and old system dynamic model

Table 1. Comparison of New Dynamic Model and Conventional Aircraft Dynamic Response Model (cont)

Characteristic	New Dynamic Model	Conventional Dynamic Model
Experimental determination of aircraft dynamic handling properties. (usually, experienced pilot-analyst team uses simulator, making run-to-run modifications to dynamic model coefficients, to evolve the required dynamic response model.)	Excellent. The new dynamic model provides for "visualizing" dynamics in terms of transfer function characteristics.	Generally poor, since conventional model typically provides little intuitive insight into dynamic response characteristics as a function of mathematical model parameters
Relative execution speed	Fast	Typically slow, depending on step size, integration algorithm, and model complexity
Sensitivity to numerical integration method selected	Relatively insensitive; only one integration (roll rate) required.	Optimum integration algorithm is a function of integration step size, word length, and system dynamics. Dynamic response can be extremely sensitive to integration algorithm and step size.

TABLE 2. COMPARISON

Equations of Motion	Conventional Model	New Model
Quantity of realtime numerical integrations required for:		
Translational equations	6	6
Rotational equations*	9 or 7	1
Detailed aerodynamics coefficients	Yes	No
Detailed autopilot model	Yes	No
User-specified transfer functions	No	Yes
Easy to 'visualize' dynamics	No	Yes
Easy experimental 'tuning'	No	Yes
Closed form solution of coordinate transformation	No	Yes

*Typically seven (7) realtime integrations if the quaternion method is used to generate the earth axes to body axes transformation, nine (9) if the direction cosine method is used.

SIMULATION RUNWAY TOUCHDOWN ZONE
VISUAL REQUIREMENTS: TEXTURAL VISUAL
CUE CONSIDERATIONS

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Capt. Kent I. Mehrer is a Computer Systems Analyst in charge of Advanced Training Software for the Advanced Simulator for Pilot Training (ASPT) located at the Air Force Human Resources Laboratory's Flying Training Division at Williams AFB, Arizona. He has been involved in ASPT operation and programming for a year and a half. Prior to this, Capt. Mehrer spent two years as a T-37 flight instructor and check pilot at Williams AFB, AZ. As project engineer for Advanced Training, he was responsible for development of automated performance measurement for several projects including the Runway Touchdown Zone Textural Study. Capt. Mehrer holds a B.S. in Mathematics, specializing in Computer Science from Portland State University, Portland Oregon.

Eric G. Monroe
Visual Systems Engineer
Flying Training Division
Air Force Human Resources Laboratory

(Photograph and Biographical Sketch - see page 1)

Capt. George H. Buckland

(Photograph and Biographical Sketch-not available)

SIMULATOR RUNWAY TOUCHDOWN ZONE
VISUAL REQUIREMENTS; TEXTURAL VISUAL
CUE CONSIDERATIONS

GEORGE H. BUCKLAND, ERIC G. MONROE and KENT I. MEHRER
Air Force Human Resources Laboratory
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ABSTRACT

Many various flight maneuvers have been studied using flight simulators with visual systems, but one which has not received much attention is the flare and final touchdown. One criticism suggested is the lack of adequate textural information in the visual scene which is needed to provide good cues for depth perception. With the flexibility and rapid variation of the visual scene content of a computer image generation (CIG) system, a detailed investigation of these visual cues is both possible and practical. The Advanced Simulator for Pilot Training (ASPT) has such a CIG system with the capability to support this type of research. This paper summarizes the engineering modifications to the CIG and Basic ASPT systems and the data collection for the first study of runway textural visual cues.

INTRODUCTION

Figure 1. Touchdown at Williams AFB

There are several problems in developing an adequate runway visual scene for a flight simulator. Many of the textural cues in the runway touchdown zone are of irregular nature, such as the tire marks on the runway (Figure 1), and they are, therefore, difficult to vary or specify in an orderly parametric system. Unless pilot performance or training effectiveness can somehow be shown to vary along some dimension of textural detail, it is difficult to convincingly demonstrate that runway texture has actually contributed to pilot performance. Also, a generalized definition of textural requirement for flight simulation is needed for decisions on cost effective designs of future flight simulators. Subjective judgements such as, "Our simulated tire tracks did or did not help," are not very useful in this regard. Ultimately, simulated tire tracks may be used, but probably after they have been related to a more general dimension of visual texture. Also, due to the CIG edge consuming characteristic of simulated tire tracks, there may be less costly ways to simulate runway textures. Therefore, a grid pattern superimposed upon the touchdown zone area appears to be a simple way to vary runway texture along a dimension of coarseness, given ASPT's current image generation capabilities.

Assessing a flight simulation visual scene in terms of its adequacy for touchdown and landing can be pursued in a number of ways ranging from student training effectiveness to experienced pilot performance. The criticism of touchdown visual information has often been stated by experienced pilots and demonstrated in their performance by their excessive vertical velocity at touchdown. Therefore, it would seem most effective to initially investigate this phenomena in ASPT, using experienced pilots who can be assumed to have reached a stable level of performance in the T-37. Considering the runway environment, this would permit assessment of the relative transfer of pilot performance from the airplane to the simulator. Next it would be informative to study the extended simulator learning curves which other researchers have reported for experienced pilots regarding the acquisition of simulator touchdown landing skills using the most promising of the previously tested touchdown zone configurations. Since learning studies are inherently time consuming in terms of pilot and simulator time, it is best to perform these studies using a minimum number of different simulator configurations. Finally, it would also be necessary to validate the training effectiveness of such simulated runways with undergraduate pilot training (UPT) students having limited flying experience. The preceding studies with experienced pilots would be more pertinent to their proficiency maintenance requirements.

Obviously, the initial phase of runway touchdown zone evaluation might consist of two or more iterative phases before suitable visual scenes were developed for the later training studies. The current study will involve only the first phase using Air Training Command (ATC) instructor pilots (IP's) current in the T-37 aircraft.

Another consideration is the motion cue at touchdown which is possibly one cue which is quite important in providing the pilot with immediate feedback information concerning his performance. Thus, it seems quite reasonable to study the different runway scenes under conditions of both motion on and off for at least the first study.

GENERAL SYSTEM DESCRIPTION

The ASPT system consists of two T-37B simulator cockpits, each cockpit with a 31-cell G-seat is mounted on a six-degree-of-freedom synergistic motion base surrounded by seven cathode ray tubes (CRT's) with special infinity optics providing a wide-angle, field-of-view (FOV) visual display. The visual scene is produced by means of a CIG technique which provides a perspective two-dimensional image of an environmental model defined in three-dimensional vector space and stored in computer memory. Unique characteristics of this CIG system are:

1. Wide-Angle, field-of-view

2. Unrestricted viewpoint position and attitude

3. Unlimited number of environmental data bases which can be modified, amended, and constructed with reasonable effort and little expense.

4. Rapid change of visual environments.

Development of Visual Scene

For this study, a set of six runways was developed; all, except the night runway, without surrounding visible objects or texture. Five runways were daytime scenes, and the sixth one was a night scene.

The basic and least detailed runway (Figure 2) consisted of a 6,000 foot long "bare bones" runway environment with the horizon, runway centerline and edges, and an aim point marking 1,000 feet from the threshold which demarks the runway touchdown zone. All surrounding visible objects and texture were removed. The second runway (Figure 3) was comparable to the ASPT "Willie" environment runway adding an overrun with markings and runway stripes and numerals to the basic runway. The other three daytime runways were the second runway adding grid patterns with three different density or coarseness levels to the touchdown zone. Using three different shades, the grid pattern was a variety of rectangular designs overlaid on the touchdown zone. The rectangular designs were scaled to present patterns of different textural edge densities. The base edge, i.e., the shortest edge of the rectangular design for the third, fourth, and fifth runways had lengths of eight (Figure 4), four (Figure 5), and two (Figure 6) feet respectively. The desired runway was selected for display by the CIG control's edge setting switch, each runway corresponding to a particular edge setting. The night runway (Figure 7) included approach lights, touchdown zone lights, and edge and centerline lights. Some lights around the runway were included to establish a ground plane and horizon. This runway was selected using the night features of the CIG control panel.

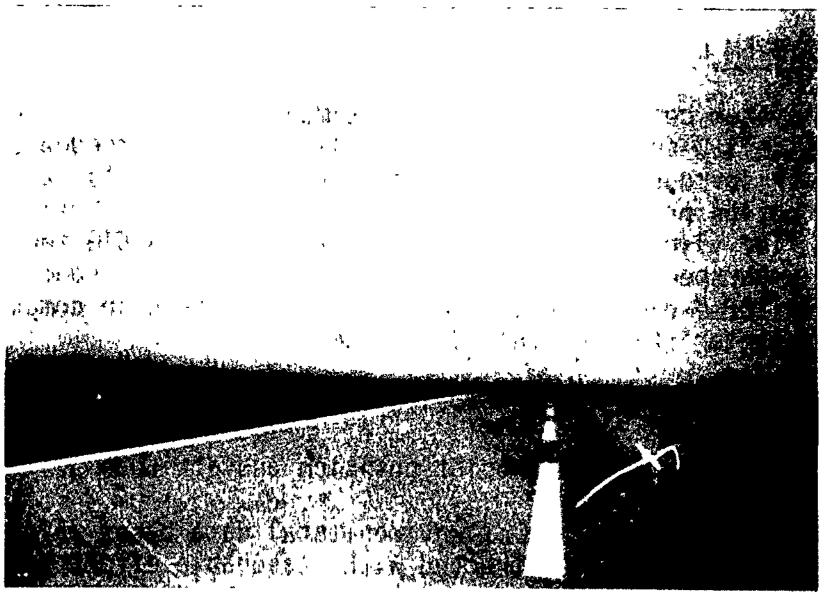

Figure 2. Touchdown on "bare bones" runway

Figure 3. Touchdown on "Willie" runway

Figure 4. Touchdown on 8-foot grid runway

Figure 5. Touchdown on 4-foot grid runway

igure 6. Touchdown 2-foot grid runway

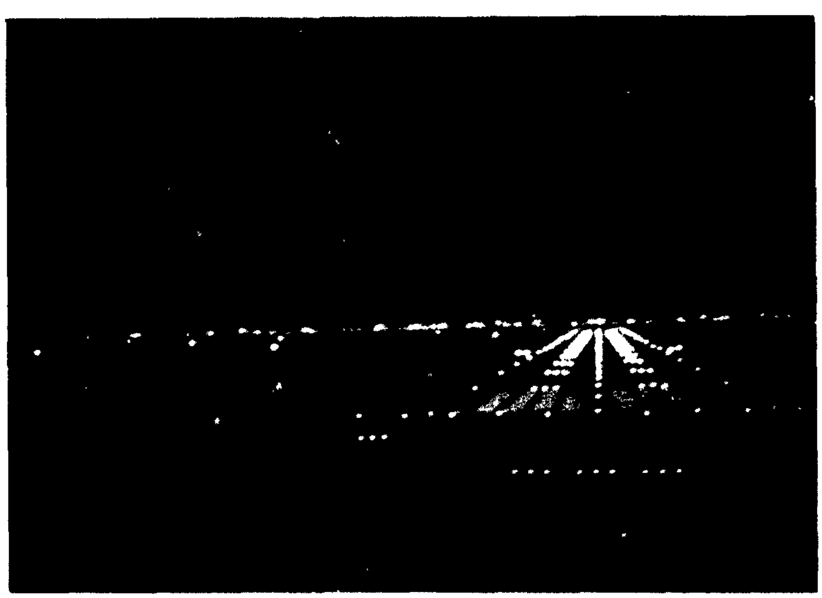

Figure 7. Short final on night runway

Development of Performance Measurement

In order to get objective data from analysis of each runway scene, the automated performance measurement (APM) system of ASPT was set up to collect data for the final approach, flare, and touchdown. The APM system samples various flight parameters at 3.75 times per second and scores these against established desired base values with percent of time outside predetermined upper and lower bounds. Also, a root mean square (RMS), minimum and maximum deviation from the base value, is calculated for each parameter being evaluated. The parameters examined for this study were airspeed, centerline deviation, and glide path deviation on final approach (Figures 8 & 9); airspeed, altitude, pitch and centerline during the flare (Figure 10); and airspeed, heading, vertical velocity, position from threshold, and position from centerline touchdown (Figure 6).

Figure 8. One mile final on grid runway

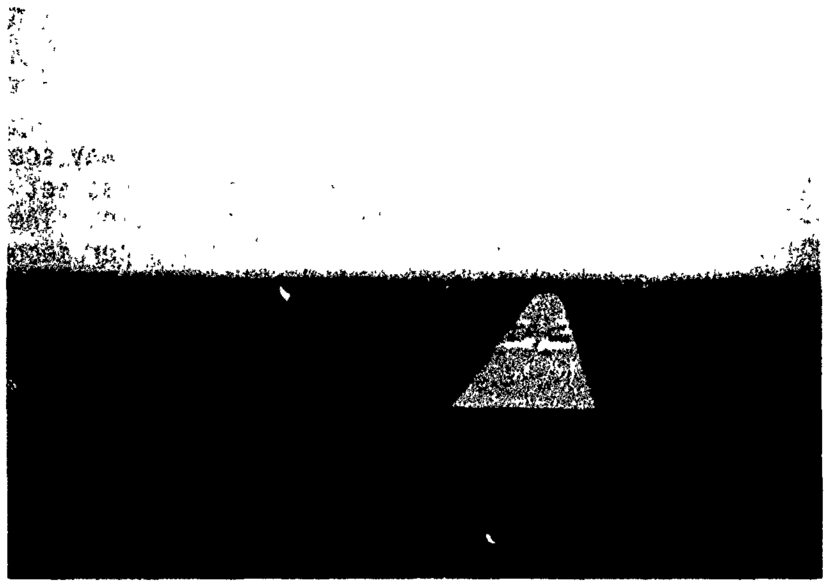

Figure 9. One-half mile final on grid runway

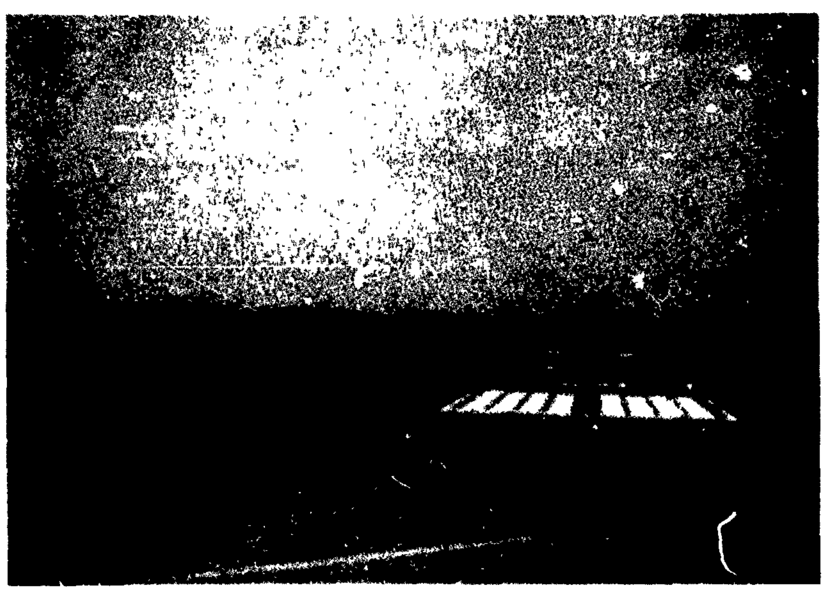

Figure 10. Over the overrun on 2-foot grid runway

Since airspeed, altitude, and pitch are constantly changing throughout the flare, special analysis and development were required. To get an idea of what these parameters do during a flare, a data recording of several parameters was made and analyzed. From this data, graphs for airspeed, altitude, and pitch against time were determined with the following relationship. Using a start time of power reduction to idle, thus starting the flare, airspeed changed linearly from 100 knots on final touchdown airspeed of 75 to 80 knots. Altitude changed linearly with two separate segments. The first started when power was pulled to idle and went for 4.5 seconds. The second began one second later and went to touchdown with the slope on the second shallow compared to the first segment. Lastly, pitch changes resulted in a "S" shaped graph starting at -1.5 degree pitch when time started and ending at approximately 10 degrees pitch when the touchdown occurred. The algorithms for these graphs were programmed and used as base values for the flare.

Along with the above data, a smoothness profile was collected which accumulated 19 pilot control inputs at a rate of 15 times per second. These inputs are from the ailerons, elevators, rudders, and throttles including selected power, RMS position, RMS movement, RMS rate, RMS acceleration, reversals, and force data. All parameter and smoothness data were saved on disc and tape for statistical analysis following the data collection phase of the study.

Data Collection

For this initial study, ten experienced T-37 IP's served as subjects. Each pilot flew the six runway types five times with motion and five times without motion. To eliminate the effect of order as much as possible, the pilots flew the sequence of runways in a completely random order with motion randomly varied within the sequence.

Each approach and landing started from a short final approach initialization approximately one mile from the runway threshold. From this point, the pilot flew the final segment, flare and touchdown attempting to land in the first 1,000 feet of the runway on runway centerline. The exercise terminated when the simulator slowed below 50 knots on rollout.

Data Analysis

The pilots' performance scores in terms of vertical velocity at touchdown and distance from the optimal touchdown point, and the variance of these scores, will be analyzed for statistical differences between runway and motion configurations using a repeated measures factorial ANOVA design. A large set of the touchdown performance measures will also be subjected to a multivariate analysis of variance in order to determine further differences in pilot performance during the touchdown maneuvers due to runway or motion configurations.

Current Status and Developments

In October 1976, engineering development started on both visual and performance measurement with development completed the end of January 77. Data collection started 16 Feb 77 with completion on 17 Mar 77. Review of the data will start the end of Apr 77 with statistical analysis due for completion by mid-Jun 77. Due to the large volume of data, there are no preliminary indications at this time.

In regard to performance measurement of the flare, it was found that each subject used different points to start the flare determined by pulling power to idle. This gave a wide range of flare scores which many subjects commented on; therefore, the flare scoring is currently being redeveloped with the possibility of using a distance from the threshold as a starting point.

DIGITAL IMAGE GENERATION:
THE MEDIUM WITH A MESSAGE

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Dr. Stark is currently Staff Scientist-Human Factors in the Link New Business Development Department. His responsibilities include the definition of training device requirements for new airborne and surface simulation systems and devices. In his career at Link, Dr. Stark has participated in the design of a wide variety of simulation systems, and has performed a number of studies of training device concepts and requirements, and has analyzed user requirements for their impact on device design.

Dr. Stark received the Ph.D. in Psychology from the Ohio State University in 1955, and is a member of the American Psychological Association, Pennsylvania Psychological Association and the Human Factors Society.

DIGITAL IMAGE GENERATION: THE MEDIUM WITH A MESSAGE

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INTRODUCTION: Simulators provide synthetic information to operator trainees, to permit them to develop the responses appropriate to various patterns of information expected to be encountered in real-world system operation. The information provided is synthesized in the interest of economy safety and convenience. These devices are called simulators because, traditionally they have attempted to provide information which appears to be the same as that observed in the real-world system environment. Realism has been a major design goal, in the expectation that it will somehow ensure learning, under appropriate conditions of practice. Many compromises have been made over the years, in the degree of fidelity incorporated in many elements of simulator design. Some of these compromises have been deliberate, resulting from essential, inherent differences between the real-world system and the practicalities of system simulation. Others have been less deliberate, amounting to acquiessence in the face of unalterable (at the time) circumstances. Some aspects of cockpit motion system design are good examples of some of the compromises made through conscious attempts to reconcile ground-based simulator capabilities, human motion perceiving capabilities and the dynamics of the flight system being simulated. Subliminal washout schemes and recent developments in sustained-g cuing have seemed to provide useful information for pilot training without resorting to the duplication of aircraft excursions and accelerations.

Unfortunately, most compromises in visual simulation system design have seemed to be of the other sort: compromises have arisen from consideration of cost, the unique capabilities of the approach in vogue at the time and the capacity of the system designer for seeing realism in his own, but not necessarily the pilot's terms.

REALISM IN SIMULATION: Realism, in the stictest sense, is too much to ask of almost any simulator, but the definition of realism varies markedly with the point of view and with the competence with which that point of view can be articulated. To the designer, visual system realism

frequently means the incorporation of as much identifiable information as possible, within the limits of the approach chosen. For the skilled pilot, concepts of realism vary widely with the flight task to be practiced and with the nature of individual needs for fidelity. Many pilots hope for simulators with the same level of scene content and complexity as is hoped for by the designer. Instructor pilots tend to think in terms of the discrete cues they point out to their students, while avoiding unreliable "gouges" which could mislead the student in actual flight operations. With experience, most pilots begin to identify the cues they really need for effective practice, and this usually does not include all of the information seen in actual flight.

Students are rarely consulted about their perceptions of reality in the flight environment, and pilots in general have great difficulty in verbalizing skills which are highly non-verbal and, at the higher skill levels, automated. As a result, extensive experience in a simulator, and intensive thought are required, after the simulator is designed, in gaining real insight into its essential characteristics.

The operation of the human visual system and its correlation with other sensory mechanisms is relatively obscure. As a result it is difficult if not impossible, for training system designers to specify visual cue requirements for the support of practice in specific visual tasks, at specific levels of trainee sophistication without making extensive extrapolations of available research and experience.

While realism has been an implicit design goal for many years in all aspects of simulation, inherent limitations in hardware and software and the rapidly increasing importance of synthetic training settings are finally directing attention away from realism and toward the perceptual and learning problems involved. Realism need not be abandoned as a goal in simulator design, provided it is recognized that realism varies with the student, the task and with the circumstances under which the task is performed. In effect, realism must be defined in terms of the perceptions of the trainee to whom a given body of task information is important at a given time.

The novice pilot perceives little of the flight environment, in the sense that he organizes the information it presents in meaningful and useful patterns. Eventually he learns to perceive selectively, and to time share his attention among

elements and patterns within the environment, whose dynamics define the flight control task at a particular time. As he progresses, he learns to incorporate more and more environmental information in his perceptions so that eventually he becomes capable of using, at one time or another, all of the information available to him. It appears that this process never ceases, since expert pilots continue to develop new and refined capabilities with more and varied experience.

In effect, the demands of the novice for realism in the training setting are limited by his ability to organize the information available to the more skilled pilot in the same setting. His demands are also limited, in most enlightened training settings, by the performance requirements placed on him, as a novice. Similarly, the demands of pilots at other stages of their development differ with their ability to perceive, and with the demands of various training settings designed to develop their capabilities to the higher degree.

LIMITATIONS IN THE MEDIA: The media developed for the support of synthetic pilot training have rarely been designed to influence specific perceptual capabilities in carefully-defined training exercises. Instead, they have been designed to do their best in ill-defined attempts at fidelity and realism. Many of the visual systems developed over the years have had the ability to portray some essential aspects of the flight environment, useful in some specific training situation, but in many cases, these systems have been evaluated for their ability to contribute in settings which were inappropriate to their unique capabilities. Each medium from Flexman's blackboard to the most carefully-detailed camera-model visual system has had unique capabilities and equally unique limitations, when employed in specific training contexts.

Many of the limitations of these systems have been inherent in the basic technology employed. The blackboard, of course, relied on changes in runway geometry to provide cues to the approach flight path. It was not able to provide size changes usually associated with reduced altitude, and it could not portray changes in the visibility and motion of textural scene elements, but at a particular stage in training, it permitted the development of some important components of the landing skill. The Cyclorama incorporated in the SNJ trainer, like Ed Link's first trainer, was useful in a limited stage of training, in supporting the development of a limited range of skills having to do with the effects of the controls.

Point light source visual systems have also been useful in some phases of training, but each of these systems had the advantage of such obvious limits that they were not expected to be very useful in any but a very restricted set of task contexts.

Camera model systems have a unique disadvantage: their limitations are not so apparent as are those of the less sophisticated approaches, because they seem so real. As a result, their application has tended to be broader than their capabilities.

The limitations of camera model systems stem in part from their inherent realism. Very little is expected of the obviously synthetic display. If it behaves like some discrete element of a real-world visual scene, in response to control inputs, it can be accepted at face value as a way of learning to operate the controls as they relate to that particular scene element. If a synthetic display looks "real", however, more may be expected of it than it can manage. Good camera model systems provide geometric, size, shape, parallax and interposition cues which are unexcelled in portraying flight path information under certain simulated flight conditions. Because of this, there is a strong tendency to expect them to do other things which the real visual world does, but which are beyond their capacities. In landing, for example, and in very low-level flight, the presence of trees, buildings, and other detail features develops an expectation on the part of the pilot for additional levels of detail which, currently, cannot be satisfactorily fulfilled.

At some place along the landing approach, the aircraft (and the pilot) make a transition from the flight environment to the terrestrial environment. Vertical velocity suddenly changes from an instrument reading having abstract meaning to sink rate, with profound meaning for pilot comfort and survival. At this point in the approach, the pilot begins to look for cues which can tell him where and how rapidly he will make contact with the runway. Geometric cues, useful in maintaining heading and vertical velocity within limits early in the approach seem less compelling at this point, than those which identify the new environment for what it is. Runway markings of known size, tire marks, grass, pebbles and lighting fixtures seems to provide the visual Gestalt needed to make the scene look real and useful, unless it is a night scene or a water scene in which these features are not expected. State-of-the-art camera model

systems do not appear to be able to provide this kind of information due to problems in scaling and in depth of focus.

FIDELITY WITH MINIMUM REALISM: A number of synthetic visual systems appear to provide useful cues for training pilots in a variety of flight control tasks with an absolute minimum of realism, in the classic sense. Regular checkerboards, pseudo-random cornfields, abstract symbols and regular horizon lines appear to fulfill basic visual cue functions, within a limited range of flight task contexts; they:

1. Correlate with some relatively invariant real-world scene element, capable of supporting some aspect of flight control.

2. Respond to control inputs in the same way the real-world correlate responds to corresponding inputs.

3. Are not complex enough to provide incomplete information which leads to conflicting cues, and,

4. Do not suggest the ability to portray more complex control events than those involving the discrete cues they supply.

Even simple visual systems can produce anomalous pilot responses, if they incorporate elements which conflict with each other, either due to limits in the media, or to the pilot's perceptual resolution of apparent illusions in the display. In a checkerboard system, 1-mile squares disappeared into the distance, near the horizon, but apparently because they were sharply-defined even at extreme range, they disrupted attitude control; the geometry was correct for the distance represented, but the haze and diminished clarity were missing. As a result, they seemed to appear too close, and to move too rapidly for their intended range.

More complex visual systems appear to be able to incorporate more conflicting cues, in their basic structure than simpler systems. Until more is known about cue priorities in various flight tasks, it will be difficult to select visual simulation media which appear as they should to adequately represent important parts of the flight environment. Film systems were especially attractive at one time because of their apparent ability to provide a great deal of scene element resolution. Experience with these systems has shown that they have great value in limited applications; in areas outside their special

and narrow bailiwick, they tend to develop response tendencies which are inappropriate in the flight situation being, ostenstibly, simulated. In general, film systems do not portray correct relative motion among scene elements, their resolution is inadequate for some tasks and their flexibility is severely restricted with respect to many flight operations.

<u>DIGITAL IMAGE GENERATION SYSTEMS</u>: Digital image systems, or computer generated image systems have their own unique limitations, but most of these are in the capabilities of the display media available; data storage and processing limits are not fixed by some inherent characteristic of the computer but by and large, by the ability of the system user and its designer to define the scene content and dynamics required for effective practice, training and learning. The message of the DIG system is relatively simple: "Tell me what you want, and I'll give it a good try." No other system has the flexibility, the storage capacity or the dynamic range of systems based on digital computation, and no other system so clearly demands that data requirements be defined prior to their mechanization. Camera model systems assume a parallelism between the real world and a scaled-down version of the real world; film systems assume a similar parallelism between the light reflected from a real world scene and the ability of the pilot to perceive and respond to elements of the scene constructed from the photochemical effects of that light. Electronic systems begin to be concerned with task cue requirements in which to apply their own unique and repetitive expertise. Each system has, in effect, a simple message: "Tell me what you need, and I'll see if I have it." Unwary users receive another message as well: "If you don't tell me what you need, I'll give you what I have." To date, only the digital systems can promise to supply most of what is needed to support the range of practice situations required in flight training, but digital systems also have another message: "If you don't tell me exactly what you want, you won't recognize what I give you."

All visual simulation media have always required, for even minimal utility, that the training demands made on them be pre-defined, but many of the definitions have been deficient in one or more critical areas: they have failed, frequently, to consider some relevant facts about simulation and training:

1. What instructors and test pilots see and respond to may not be what a particular type of student sees and is capable of responding to.

2. Pilots change in their perceptual tendendies and capabilities, with training and experience; they change in their ability to respond to visual and other cues, whether they correctly portray a real-world relationship or not.

3. Simulators do not automatically sense the intent of the designer; they are more than capable of bringing stimuli to training situations which the designer did not really intend them to provide. For example, systems which depend on the distortion of areas parallel to the ground plane also distort areas in planes which are not parallel to the ground plane.

4. Visual simulation media universally leave out scene elements and/or dynamics which are normally present in the real-world correlate of the scene. The disturbing aspect of these deletions is that, from the point of view of the student pilot, they are frequently irrational. A system which displays buildings, but no windows, oceans with no waves and ridges without occlusion have limited applicability if these deletions are not to incite unflight-like behavior.

These and other conditions concerning the practice and learning of flight control skills will require special and insightful attention in the programming and display of digital visual information. Even though these systems can (1) store and display on demand thousands of discrete points, (2) connect with a line those which need to be connected, (3) connect lines to make surfaces, (4) shade, texture and color those surfaces, (5) smooth the edges between surfaces and (6) hide some points and surfaces behind others, they need to be told in detail which of these things to do, and when and where to do them.

No visual system can provide all of the information available in many visual scenes observed in real-world flight. Each system must delete some of the information which pilots normally see. Traditional systems delete what they cannot portray. With few exceptions, digital systems need delete only that which is not needed for a given training task. Finally, the question of what is really needed must be answered in detail. It can be answered experimentally, but some insight and imagination should be expended first. A number of important questions can be answered, given some effort.

1. What is it that digital image systems cannot do? In general, they cannot match the resolution capabilities of the pilot's eye. Like other systems, they probably cannot display images of the small scene elements the pilot sees on the surface of the terrain, and in the surfaces of other aircraft. In addition, digital systems are unable to represent the almost infinite variety of shapes, colors and shadings typical of real-world flight, especially at low level.

2. What do these limitations in digital image systems have to do with their potential training value? At this point, another series of questions must be answered, concerning the specific percepts and skills required of the student at the level of training under consideration, and the part played by visual scene elements in both the practice and the learning of those percepts and skills. So far little attention has been given to the function of specific environmental information in the exercise of control, and to the function of various parts of the information available, in the learning of control skills. Instructor pilots' insights are of value here, as they search for ways to focus the student's attention on relevant information in various tasks and maneuvers, and at various levels of training.

3. Since all visual cues cannot be provided, regardless of the medium chosen, what will be the effect on learning of the deletion of specific parts of the normally available information? This is a difficult question to answer without extensive experimentation, but insight can be gained by reviewing the experiences of pilots who have flown in limited visibility, over water, with restricted fields of view, over deserts and snow and in other circumstances in which normally-available cues were missing.

4. Can the effects of perceptual conflicts resulting from the deletion of normal cues be avoided by teaching the task in smaller parts than are usually approached? The simulator provides such a unique teaching environment, that it is unlikely that its most effective use will result from its employment as simply an airplane substitute. It will be found that many limitations of the simulator in "simulating" the flight environment are in fact advantages from the point of view of systematic and progressive skill development.

TASK CUE REQUIREMENTS: While DIG systems have great capacity and flexibility, they demand the definition of specific cue requirements for each flight task, skill, skill level and flight regime. In general, visual cues perform something like

seven different functions in normal flight control. We do not know all of the ways visual cues perform these functions, but before digital, or any other visual system can be efficiently designed, it will be necessary to find out how the cues they can provide, can facilitate training in visual flight tasks.

1. Attitude Control - Extra-cockpit visual cues are particularly effective in attitude control because of their inherent magnitude and because they are available when the pilot is not able to look into the cockpit, as in takeoff, landing and air combat. Visual cues in the periphery of the visual field are particularly effective due to the sensitivity of the peripheral retina to the relative motion of visual scene elements.

2. Geographic Orientation - Generalized visual cues are used in performing basic combat and aerobatic maneuvers, in the control of attitude, heading, and flight path. Visual cues on the terrain surface provide information about initial heading, heading rate and terminal heading in straight and level flight, turns, stalls, in recoveries from unusual attitudes and in aerobatic maneuvers.

3. Contact Navigation - Contact navigation involves three basic task elements, each requiring the portrayal of identifiable real-world visual features. First, the pilot must recognize features and correlate them with maps and charts of the represented area. Second, he must learn to discriminate among features whose similarity could lead to confusion. Finally, he must fly around the landmarks and features in the navigational area, performing the flight control, communications and planning functions associated with visual navigation. In addition, contact navigation requires training in various kinds of visibility conditions, in which the pilot learns to discriminate among visual cues when they are marginally discriminable.

4. Ground Velocity/Flight Path - In the takeoff, traffic pattern and final approach visual cues to velocity involve the breakout and relative motion of textural elements, as observed in real-world flight. Motion parallax among elements is important in representing ground speed and the path of flight in the landing pattern, but at very low level (0-200'), the pilot learns to judge speed and flight path through the recognition of details and detail motions which are unavailable at higher altitudes.

Visual cues to velocity and flight path are used in flight control and in short-term flight planning. Changes in object size, surface detail and in the relative positions of individual scene elements tell the pilot his heading, bearing and distance from each scene element and, in effect, the amount of time and space available at any given time to perform the tasks required at that particular time.

5. Altitude Rate - The scene elements providing visual cues to altitude rate seem to vary with altitude. At altitudes about 200'-300' changes in the apparent sizes of terrain and cultural features provide gross cues to rate of ascent or descent up to, perhaps 15,000 feet. These cues are not adequate in controlling altitude, but do provide confirmation of vertical velocity in aerobatic maneuvers, as in the loop, split-S, immelman and other maneuvers in which altitude changes rapidly.

Low altitude cues to altitude rate include those arising from changes in the apparent sizes of scene elements on the terrain. They also result from the rates at which objects in the foreground appear to move with respect to those in the background, and from the rates at which objects occlude each other. In addition, the appearance of objects and surface details which are too small to be seen at higher altitudes provides strong cues to altitude rate, particularly in the landing approach. Geometric cues, resulting from changes in the shape of the image of the runway are good cues to altitude rate on final, but for many pilots, the breakout of details appears to be a stronger source of information about proximity to the runway and the flare point.

6. Closure Rate - In taxiing, formation flying, air combat and in takeoff and landings, visual cues provide the information needed to establish the rates of closure between two aircraft, the aircraft and in obstacle and the aircraft and various points along its ground track. Cues to closure perform four basic functions: first, they differentiate the points in space toward which, or away from which the aircraft is moving. Second, they provide information about the rate at which relative motion is taking place and, more important, they help to establish the amount of time and space remaining in which the pilot must turn, slow down, speed up, climb or descend.

Formation flight involves minute changes in visual information resulting from changes in the distance and position of the lead aircraft in the pilot's field of view. As the

lead aircraft moves, its apparent shape and the spatial relations among elements of the aircraft image change. In addition, the visibility and legibility of surface details provide information about relative position, range and closure rate between the two aircraft.

7. Obstacle Clearance - In ground operations and in formation flying, visual scene elements provide information needed in avoiding obstacles in the aircraft's path. In real-world taxiing operations, the pilot regulates speed and turn radius to avoid contact with obstacles along the taxiway, by noting the velocity with which surface features and objects move across his field of view. He also watches the motion of the wing tip with respect to obstacles and surface features. Surface elements serve two functions in taxiing and obstacle clearance. The motion of surface features denotes ground velocity, and continuous features such as concrete joints and taxiway paint lines are useful indicators of distances to objects in the foregound. If a straight line appears to be 50' from an obstacle in the distance, staying on that line will assure that the pilot is 50' away when he passes that obstacle.

Object size and motion parallax among objects are also unique cues; size cues are most useful when they are associated with images which are recognized by the pilot as representing specific real objects. During turns, relative motion among objects in the foreground and the background can be extrapolated to provide information about the position of the aircraft with respect to other objects.

VISUAL CUE SIMULATION: Unfortunately, there are more ways of representing the visual cues which perform these functions than there are ways of simulating the visual environment of the pilot. A great deal of experience exists in the simulation of visual cues, which can provide some insight into the most effective way of providing visual scene elements in a variety of visual task training situations. Some of the more general information available in the simulation of visual cues is summarized as follows:

1. Attitude Control - Basic attitude control requires a horizon line and some differentiation between the terrain and the sky. Pitch and roll are controlled by comparing reference points on the aircraft with the horizon. In maneuvers requiring control of yaw, some discrete reference is required on or below the horizon, although discrete control of yaw is frequently important in maneuvers where the visual scene may include only undifferentiated sky.

Field of view is important in determining the effectiveness of attitude cues; in most maneuvers, the horizon should extend to at least 90° to one side of the pilot's normal line of sight, to provide peripheral cues to roll rates.

Some terrain texture and some of the normal cues to distance, in the form of haze and the change of size of terrain elements permit realistic interpretations of horizon motion in terms of attitude rates.

A clearly defined horizon and a featureless terrain tend to appear too close, resulting in inaccurate controls of roll rates. When the terrain appears to be at a realistic distance, roll rates are more accurately perceived and controlled. Terrain elements changing in size with range, and disappearing gradually in the haze enhance the impression of realistic distance relationships.

2. Geographic Orientation - Visual cues to geographic orientation do not need to be identifiable as representing real objects or features. They do need to contain unique elements which permit the student to align the aircraft on a specific heading, to take up a reciprocal heading and to align the aircraft on a heading orthogonal to the entry heading. Unique, discrete features are also required to act as points around which specific maneuvers are flown, as in a barrel roll or lazy-8 or in flying a traffic pattern. Practice at this stage of visual flight control does not require the portrayal of real landmarks for local area identification or contact navigation.

3. Contact navigation training requires visual scene elements representing major terrain and cultural features. These elements must be recognizable as specific map features, and must be complex enough to require specific training in discriminating among similar features. They must be visible at realistic ranges and altitudes, and they must vary in detectability and recognizability with variations in visibility and lighting. Surface detail requirements are minimal, except in low-altitude pattern flying where the breakout and relative motion of the surface details of familiar features serves as cues to altitude and velocity. Color is significant in enhancing apparent contrast among features, in their detection and identification and in the estimation of range and time-to-go with respect to features at the limits of visibility, since colors tend to fade toward blue at extreme ranges.

4. Ground Velocity/Flight Path - At low altitude (200'-2000') generalized visual cues to ground velocity and flight path can be provided by simple objects which change in apparent size and shape as they move around in the visual scene. Three-dimensional objects provide additional cues in the form of enhanced motion parallax cues and mutual occlusion. At altitudes below about 200', as in landing approaches, ground velocity and flight path cues are provided by the appearance and gradually increasing clarity of details which cannot be seen at higher altitudes. In the final approach, the scene elements on the surface of the runway in the touchdown area remain stationary. As the flight path is changed to change the area in which touchdown would otherwise occur, this area of stationary elements changes. As a result, textural elements in the runway surface are useful cues defining the touchdown zone.

Scene elements having known sizes and size relationships are especially effective because when the element and its size are known, its perceived size, and changes in its apparent size provide information about range and range rate.

5. Altitude Rate - Familiar objects and features in the visual scene provide cues to altitude rate, as they change in size and orientation and in the amount of detail visible at various altitudes. At high altitude, where vertical velocity is incidental to the training task, simple generalized shapes provide adequate altitude rate information. At low altitude, detail and textural information become important. Geometric cues, motion parallax among scene elements and the apparent velocity of scene elements as they move into the foreground are adequate for simulator control in the landing approach, but they are not adequate in assuring skill transfer to the aircraft. In actual flight, more complex cues to altitude rate are available and must be incorporated in the student's perception of the landing situation. As a result, detail and textural cues portraying those available in the real-world must be introduced at some point in the training situation.

6. Closure Rate - Cues to closure are provided in two general ways. First, changes in the size of objects in the visual scene denote rates of closure in relatively gross terms. In addition, changes in the apparent velocity of objects in the foreground and in the background provide closure information. Perception of closure is somewhat more accurate if the objects are familiar, and of known size. The second general cue to closure is in the resolution of surface detail in the individual elements of the visual scene, and of

small objects which become visible only at close range. The first type of cue (size change) is adequate for long range (2000'), but both kinds of cues are needed to represent relevant flight control tasks at the shorter ranges. When scene elements are recognizable as representing real-world objects, they must display at least some of the surface details pilots learn to associate with them in the real world, to avoid the triggering of inappropriate pilot responses. When the scene elements do not represent real objects, pilots can use them in learning to fly the simulator, but transfer of simulator skills to the aircraft may be degraded.

The perception and control of closure rate in formation flying requires both geometric and detail cues. The apparent shape and aspect of the lead aircraft provides gross cues to relative motion, while detail cues operate in two general ways, to provide information for fine control of relative motion. The alignment and relative motion of components of the lead aircraft image, much as the aileron hinges, the canopy bow, the pilot's head and the wing filler and the various surface decals provided useful cues to the precise control of closure. In addition, the relative visibility of these features is also a useful cue to relative distance and to rate of closure. Generalized cues can be used to teach the simulator skill, but scene elements which are recognizable in the real world are essential to optimum transfer.

7. Obstacle Clearance - Three-dimensional objects of known size and shape, having familiar surface details are required for training on obstacle clearance during taxiing and flight operations. In taxiing, surface markings are required to permit accurate sensing and control of velocity and turn radius, and to facilitate the perception of obstacle position with respect to the ground path. Visual cues to the location and motion of the wing tip are desirable, but are likely to exceed the minimum field of view required in other more critical tasks. Without wing tip cues, simulator taxiing should be limited to areas having widely-spaced obstacles, and good surface markings. Obstacle surface detail markings should be provided to denote obstacle distance consistent with safe wing tip clearances.

In formation flying, size, shape and aspect cues are critical in providing information about relative distance and flight paths. Surface details are also important, in providing cues to range and range rate. In all cases, cues must be recognizable as familiar scene elements, to enhance transfer of simulator skills to the aircraft.

CONCLUSIONS: The major advantage of Digital Image systems is their flexibility in providing almost any kind of visual information required. Another equally important advantage is the necessity of defining beforehand the information really required in detail. Important training and operational economies can be realized if specific information requirements can be defined for individual classes of tasks and for specific task skill levels. More important, training effectiveness can be greatly improved, particularly in landing and in tactical operations, if, finally, the visual phenomena occurring in these regimes can be defined for systematic development and incorporation in the response repertoires of the flight crews whose success will depend increasingly on the quality of the training process.

Knowledge and insight with respect to minimal visual task cue requirements, the effects of perceptual constancies, the origin and nature of visual illusions and the nature of the interactions taking place among the various sensory modalities in manual flight control are currently incomplete. Specific research in these areas is essential in optimizing the design of any visual system. As data are collected to indicate the best application or DIG systems, a better understanding will be gained of the capabilities and limitations of other approaches to visual simulation. The result will be further economies in the allocation of training functions to all visual system approaches.

COMPUTER IMAGE GENERATION USING
THE DEFENSE MAPPING AGENCY DIGITAL
DATA BASE

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Mr. Hoog received a Master of Engineering Degree from the University of Louisville in 1975, a Master of Science Degree from the University of Dayton in 1972 and a Bachelor of Electrical Engineering Degree from the University of Louisville in 1964. He has also attended UCLA and completed several USAF short term courses.

Currently Mr. Hoog has the engineering responsibility for Project 1183. He also advises other engineers and managers in radar simulation requirements, simulation methods and serves as a focal point for data base activities. Mr. Hoog has been deeply involved in the revision process of the DMA DDB production specification and participated in ASD's recent development of general radar simulation requirements.

Previous assignments at Aeronautical Systems Division include ECM and ECCM simulation. Mr. Hoog participated in the development of the Simulator for Electronic Warfare Training (SEWT), and was responsible for acceptance testing and installation of the ECCM simulator for BUIC. He has also worked on systems analysis and definition of an Air Traffic Control Trainer.

Prior to joining ASD, Mr. Hoog served with the USAF as an engineer with the Space and Missile Systems Organization (SAMSO).

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Currently, Captain Stengel is the Offensive Systems Project Engineer for the B-52 Weapon System Trainer. He also participated extensively in the development of general radar simulation and navigation system simulation requirements. He has been deeply involved in the revision process of the DMA DDB production specification.

Prior to his assignment at ASD in 1975, Captain Stengel spent three years as a B-52 radar navigator in the Strategic Air Command

COMPUTER IMAGE GENERATION USING THE DEFENSE MAPPING AGENCY DIGITAL DATA BASE

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INTRODUCTION

One of the most significant tasks in the production of a Computer Image Generation (CIG) system is the development of the data base. This effort is particularly difficult because many of the tasks the data base supports require a high degree of ground truth. With the advent of more and more CIG systems and the desire of the users to have increased data base coverage, the problem of obtaining a high integrity ground truth source data base covering large geographical areas has arisen.

This paper addresses this specific problem and offers a solution. Futhermore, several possible methods for utilizing this data base are suggested. A general approach is presented and problems unique to specific situations are not addressed. The methodology discussed in this paper does not necessarily represent a complete ASD position nor a recommended approach. This is left to the requirements for each particular program. Also, this paper is written from a simulator acquisition organization's viewpoint and does not necessarily represent a DMA position or recommended approach. It should also be noted that the DMA data base production specification is presently being revised and thus only the basic elements of the data base are discussed. This paper also addresses some long range possibilities regarding the use of the data base and some of the implied data base content is that of the authors.

PRESENT METHODS OF DEVELOPING GROUND TRUTH VISUAL DATA BASES

There are basically two classes of data base modeling problems. One class is where the ground is unimportant such as air-to-air tactics, refueling, formation flying, etc. The emphasis is generally on another aircraft, and the ground, if modeled at all, is merely background. This class of data base modeling will not be discussed further in this paper. The other class is where the ground is highly important such as takeoff and landing, air to ground tactics, low level navigation, etc. In many cases it is also very important that the model represent ground truth, because of the crew member's familiarity with certain geographical areas and the need for the scene to correlate with other sensors which do require ground truth information.

The quality of the visual data base model is highly dependent on the source materials available from which the ground truth model can be developed. This material often consists of maps and charts; city, town and air base planning documents; civil engineering drawings; etc. Depending on the size of the required model and the number of models to be delivered, the collection of the source materials can be a real headache. Another significant task is the analysis of the source materials to define the various features and the generation of the visual data base. All these tasks are very time consuming and tedious. In order to automate the job to any significant extent, a large capital investment would be necessary.

The remainder of this paper will discuss a source data base currently being developed on a world-wide basis which can significantly simplify the problems stated above. We recognize that the DMA DDB is not presently the complete answer to the source data base problem for visual systems, but if used properly it can be a significant step in the right direction.

ORIGINATION OF THE DMA DIGITAL DATA BASE

DMA's FUNCTION

The Defense Mapping Agency (DMA) is the DOD organization responsible for Mapping, Charting, and Geodesy (MC&G) products for DOD. DMA was formed in 1972 with headquarters in Washington D.C., the Aerospace Center in St. Louis (formerly the Air Force's Aeronautical Chart and Information Center), the Topographic Center in Washington D.C. (formerly the Army's Topographic Command), and the Hydrographic Center in Washington D.C. (formerly the Navy's Oceanographic Office). One of DMA's MC&G products is a digital data base which is used to support a variety of DOD programs. Presently, radar simulation programs have levied the largest workload on DMA, accounting for 18 million square nautical miles of digital data base requirements.

PROJECT 1183

Project 1183 is an engineering development of a Digital Radar Landmass Simulation (DRLMS) system which is serving as an evaluation tool for determining future ground mapping radar simulation and data base requirements. There are two major development efforts within the project. One is the DRLMS system itself, and the other is the DMA Digital Data Base (DDB).

The 1183 DRLMS system consists of special purpose hardware, general purpose control computers and software. The general purpose computers control the radar simulation and flow of data. The special purpose

hardware consists of four moving head discs which store the gaming area, four fixed-head discs which store the potentially viewable data around the aircraft, data retrieval, radar equation and azimuth beamspread subsystems. The On-line DDB stored in and processed by the DRLMS system basically consists of elevation and reflectance values formatted to be efficiently processed and displayed in real time.

The On-line DDB (data processed by the system) is derived from a source data base, the Off-line DDB developed by DMA, through a transformation program. The purpose of the transformation program is to format and order the data for real time use and assign reflectance and elevation codes. The concept of a single source data base with transformation programs for specific applications is to permit the simulation of individual radar characteristics, primarily different resolutions, allow various design approaches and avoid all the problems (especially cost) of developing a new source data base for each program. This concept has been demonstrated by the fact that at least three different radar simulation programs, Project 1183, the A-6E Simulator and the Experimental Radar Prediction Device (ERPD), have used the Off-line DDB in different ways.

The DDB production specification was originally developed by DMAAC and ASD, published in May 1973 and was later revised in September 1974.[1] At the outset of Project 1183, ASD recognized the potential of the Off-line DDB to support other than radar simulation even though the descriptors used were largely radar oriented. The Off-line DDB consists of two multi-level files - a terrain elevation file and a culture file.

The terrain elevation file consists of three different levels of terrain elevation values; i.e., three arc second spacing, one arc second spacing, and one-half arc second spacing. This equates to approximately 300 feet, 100 feet, and 50 feet spacing respectively at the equator. Because of longitudinal convergence, the earth's surface was divided into zones. Therefore, the spacing is slightly different at the higher latitudes although the linear separation is approximately retained.

The culture file has six different levels defined although the higher resolution levels were used sparingly because of data base production costs. The coarsest level of data exists everywhere with higher resolution data produced only for areas of interest. Minimum size criteria are generally a function of the feature's predominant surface material. There are special criteria for unique significant features such as bridges, isolated structures, radar reflectors, etc.

A cultural feature may be described as a point (feature represented by a single point, e.g. radar reflector), linear (feature represented by two or more connected points in the horizontal plane, e.g., fence), or areal (feature represented by three or more connected points in the horizontal plane, e.g. building). Feature descriptors include the following:

a. Surface Material - Differentiates between features whose surface is predominantly metal, wood, concrete, soil, vegetation, etc.

b. Feature Identification (ID) - Provides basic physical description of what has actually been encoded; e.g., water tower, office building, bridge, etc.

c. Orientation - The angular distance between true north and the major axis of a feature encoded as a point.

d. Height - Feature height above or below terrain.

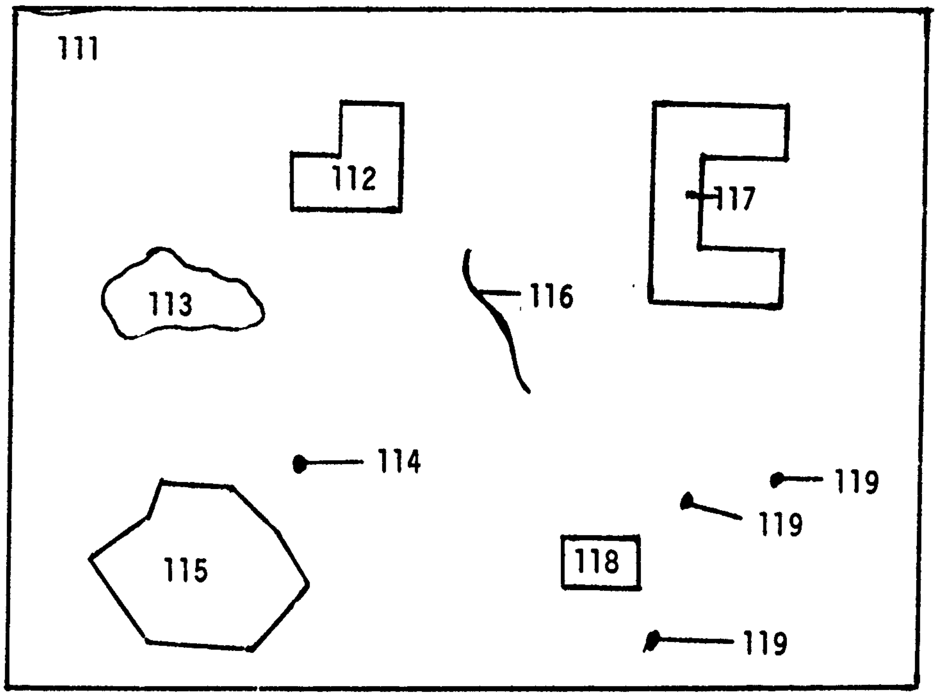
e. Percent Tree Cover - The estimated amount of tree cover (foliage) covering an areal feature representing a group of individual structures such as a mobile home park or residential area.

f. Dimensions - Length and width of a feature encoded as a point (length and width of linear and areal features are inherent to their encodement).

A single feature may be something as small as a radar reflector or as large (several hundred square nautical miles) as the background for an entire manuscript such as soil, sand, etc. Figure 1 provides an example of how an Off-line DDB manuscript might appear and an explanation of the data content. This 1183 Off-line DDB cannot be completely summarized in a small space and therefore is not addressed further here.[2]

SOME PRELIMINARY DDB CONCLUSIONS

Even prior to the conclusion of the Project 1183 test and evaluation phase, some preliminary conclusions are being reached. These are results of actual radar scope photography analysis, comments from radar navigation and weapon systems officers during acceptance tests and use of the DDB during the entire development. Some apparent inconsistencies in the intensity of known reflectors have indicated a need to further define individual objects through expanded use of the feature identification and surface material descriptors. Dimensional criteria for some features will be modified - some tightened and some relaxed. The user of the DDB should not be dependent on internal DMA DDB



111	Normal Soil
112	Commercial Building
113	Lake
114	Antenna
115	Apartment Complex
116	Embankment
117	School
118	Substation
119	Power Pylons

Point Feature Example - Feature Analysis Code 114
Surface material, feature identification, height, orientation, length/width, center coordinate

Linear Feature Example - Feature Analysis Code 116
Surface material, feature identification, height, directivity, width, coordinates

Areal Feature Example, Single Structure - Feature Analysis Code 117
Surface material, feature identification, height

Areal Feature Example, Several Structures - Feature Analysis Code 115
Surface material, feature identification, height, percent tree cover, percent roof cover, structures/square nautical mile, coordinates

Figure 1. Sample Off-line DDB Manuscript

production methods. This is necessary to allow DMA to modify production techniques to take advantage of state-of-the-art developments. The most important conclusion is that the concept of using the DMA DDB does work. It has been used successfully by more than one program. The revision to the DMA DDB production specification will reflect many detailed findings.

DOCUMENTED APPLICATIONS OF THE DMA DDB

As was mentioned earlier, ASD had early thoughts of using the Off-line DDB for other than radar simulation. The feasibility was demonstrated through a small study effort which resulted in the simulation of some infrared scenes of a portion of Las Vegas.[3] The study included a comparison of actual infrared scenes with simulated scenes using a simplified algorithm. This demonstration showed that the DMA DDB had the potential of fulfilling the need for a multispectral sensor simulation source data base.

Through the Advanced Systems Division of AFHRL, ASD cosponsored some studies for infrared and low light level television sensor simulation using the DMA DDB terrain elevation file.[4] Two different approaches were examined, a scan converted radar simulation and a CIG simulation. This study also included a comparison of simulated and actual scenes. Again the conclusion was that the DMA DDB had the potential of fulfilling the need for a multispectral sensor simulation source data base.

Even though the DMA DDB was radar oriented, these studies along with other independent developments showed that it was capable of supporting not only sensor simulation but also visual simulation. It was recognized that some improvements would have to be made, that the DDB might be used differently than for radar simulation and that the data base would have to overcome the stigma of being called a "radar data base."

EXPANDED USE OF THE DMA DDB

FUTURE APPLICATIONS

With the maturation of DRLMS, the development history of Project 1183, the demonstrated usability of the DMA DDB and an influx of many DRLMS requirements, ASD undertook a detailed examination of radar simulation requirements. This resulted in a new ASD general specification which formed the basis for several recent DRLMS procurements, namely the C-130, B-52/KC-135, and B-1. A significant part of this undertaking included analyses of the DMA DDB and resulted in a more complete definition of DDB requirements and expanded transformation program requirements. Presently, we expect some further improvements for future DRLMS procurements starting with the F-16.

The B-52 Weapon System Trainer (WST) program includes the development of the Electro-Optical Viewing System (EVS) simulation. The requirements for this simulation include the need to simulate a large gaming area. It is required that the DMA DDB be used as source data similar to the way it is used for radar simulation. This means a transformation program is required to produce the EVS DDB stored in the simulator. Since this EVS simulation will use CIG technology the results will be directly applicable to visual simulation.

To date, the DMA DDB has not been specified to be used in any ASD visual systems. However, the C-130 visual system specification will require the DMA DDB to be used in some form. Project 2360, Fighter Attack Simulator Visual System (FASVS), will also utilize the DMA DDB as well as other visual procurements.

As was stated earlier the DMA DDB will not presently satisfy all the requirements of a visual source data base. Furthermore, the DMA DDB may not be available for some required geographic areas. Thus there is a need to be able to create visual data bases from both DMA source data and other source data as well as to selectively augment the DMA DDB. Some of the cues needed in the resultant visual data base are discussed in another paper presented at this conference.[5]

POTENTIAL IMPROVEMENTS

As experience is gained using the DMA DDB for CIG visual systems, it can be expected that certain necessary improvements to the data base will be identified. The structure of the culture file in particular is such that a great deal of expansion and growth is possible. Recommended improvements when identified can, therefore, be accommodated. Several examples describing areas of potential improvements are discussed.

The feature ID descriptor provides the most amount of useable information for any given feature. The present file structure permits up to 1023 different feature IDs to be assigned; however, based upon present requirements, far less than 1023 are actually being used leaving considerable expansion capability. For example, airfield control towers in general are given one feature ID. Growth of the feature ID list, however, could permit differentiation among different kinds of control towers.

As previously described, the DMA DDB presently consists of two multi-level files with specific dimensional criteria. Future requirements defining the information density needed for individual applications will provide the basis for revising the resolution and detail to be contained. The information density presently being provided should not be interpreted as being fixed and rigid.

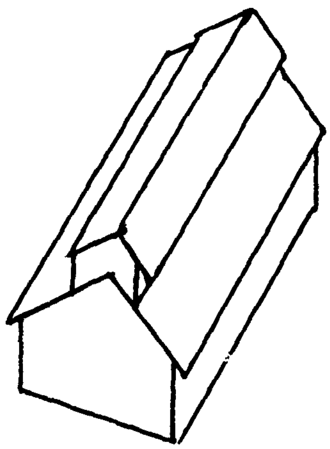
The production specification for the DMA DDB has provisions for including unique significant features based upon special criteria. Up until this time, the criteria have been based primarily upon radar significance. It should be pointed out, however, that unique significant features included for radar; e.g., bridges, islands, runways, etc, are still important for visual. As visual data base requirements are more precisely defined, the unique significant feature category could be expected to grow.

CIG DATA BASE CREATION USING THE DMA DDB

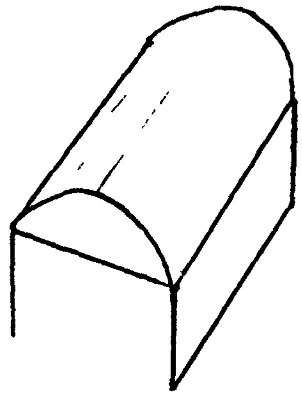
ENHANCEMENTS TO THE DMA DDB

As previously stated, it must be understood that the DMA DDB will not be self sufficient for supporting CIG requirements. However, there are numerous enhancements that can be made.

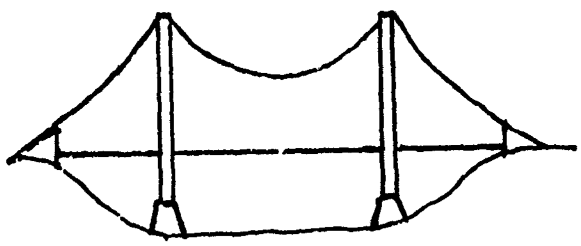
Generic modeling is one solution to the problem of having to create each cultural feature by hand as part of the data base creation effort. The concept of generic modeling is based upon the creation by a CIG contractor of uniquely defined cultural features to be contained as part of a library collection. Each feature would correspond to a feature ID defined by DMA. For example, a suspension bridge of generic design would be created by hand, stored within the library, and assigned the appropriate feature ID. However, the basic dimensions of the bridge; i.e., length, width, and height, would be represented by variables. Figure 2 provides typical examples of how generic features might appear. When the transformation process of a specified geographic location is actually performed and a suspension bridge identified by its feature ID is encountered, the generic suspension bridge model would be automatically extracted from the library and inserted into the data base file. Based upon data contained within the DMA DDB, the bridge would then be assigned a geographic location, orientation, specific dimensions, and a surface material. There are several advantages inherent to generic modeling. As previously stated this concept greatly reduces the need for continuous hand modeling during data base creation. This, in turn, permits an automated transformation program to be used and, therefore, reduces data base creation time. However, several limitations must also be understood. First, generic models are most appropriate for DMA cultural features which represent a single real world feature, and not for groups of features lumped together as an areal feature according to DMA's data base creation rules. For example, it would be somewhat unrealistic to represent a one square mile residential zone as a single split level home with 36 million square feet of floor space. Second, unique, one of a kind features, such as the Gateway Arch in St. Louis or the Landmark Tower in Las Vegas would not conveniently fall into a generic classification and would have to be hand modeled. Finally, if the data



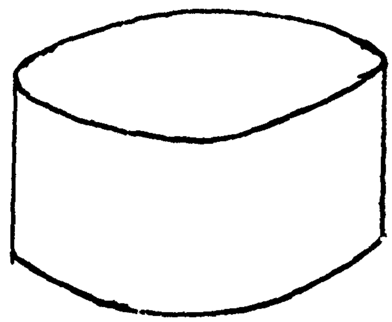
a. Industrial Building
(Gable Roof and Monitor)



b. Hangar
(Curved Roof)



c. Suspension Bridge



d. Storage Tank
(Flat Roof)

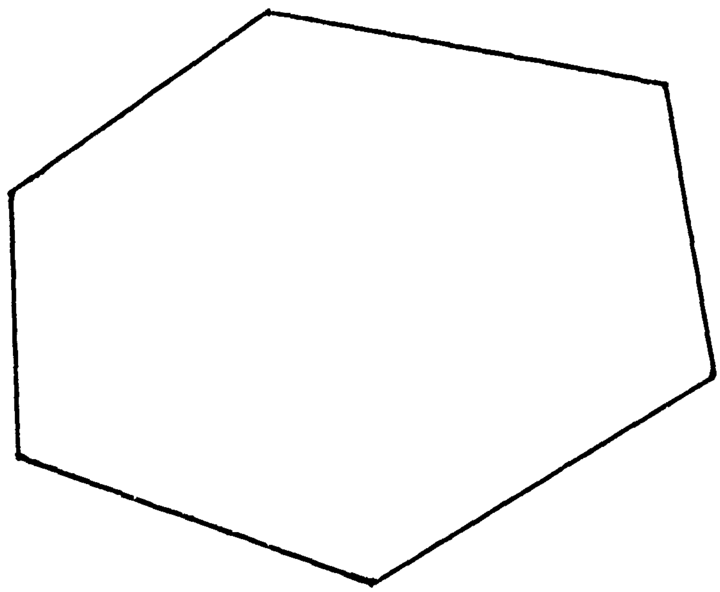
Figure 2. Examples of Generic Figures

base gaming area will cover a restricted geographic area within which certain features may be well known to the pilot, such as an airfield and local area, it may be desirable to spend more time hand modeling features from an additional data source instead of relying on the generic models.

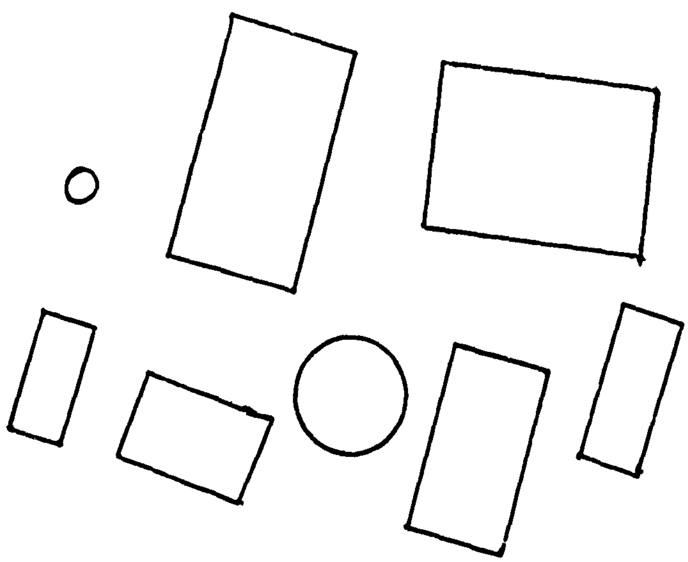
Although the color of features is not explicitly included within the present DMA DDB, the feature ID and surface material category do provide a means for inferring color. For example, a feature identified as a forest and one as a lake, might appropriately be assigned a shade of green and blue respectively. A storage tank identified as being made of metal might be assigned silver, and residential housing units predominantly constructed of wood might be randomly assigned a variety of typical colors. In addition, if seasonal effects are desired, the time of year, as well as the feature ID or surface material would be considered. For example, the difference between deciduous and coniferous trees being represented in the winter could be accommodated. The entire process of color assignment could be considered analogous to reflectance code assignment for a radar data base.

Synthetic breakup is a concept presently being developed by ASD for the enhancement of radar data bases. This concept, which could be applied to the DMA DDB, is based upon statistically selected, randomly generated synthetic features which are correlated with descriptors contained with the DMA DDB. Synthetic breakup is intended to enhance the larger DMA areal features representing groups of real world features and could complement the procedure of generic modeling for CIG applications as previously described. Figure 3 provides a two dimensional example of how an areal feature could be synthetically enhanced. Figure 4 provides a three dimensional example of how generic modeling could be applied to the synthetic breakup. For those areas of a CIG data base gaming area which do not necessarily require a precise ground truth representation, synthetic breakup would provide an information density to the data base which would then better support CIG requirements. This in turn reduces the requirement for higher level (finer resolution) data needed just for the sake of increased data content and, therefore, increases the availability for data for large data base gaming area requirements. It should be pointed out, however, that in areas of specific interest; e.g., target areas, airfields, etc, the more precise levels of data would be required.

Techniques commonly used today for CIG system enhancements; e.g., texture, smooth/curved surface shading, etc., are still important regardless of the data base source. The DMA DDB does, however, provide information which can assist in deciding when and how these processing enhancements should be applied. The spatial frequency, intensity, and



a. Areal Feature Prior to Synthetic Breakup



b. Areal Feature After Synthetic Breakup

Figure 3. Synthetic Breakup Enhancement

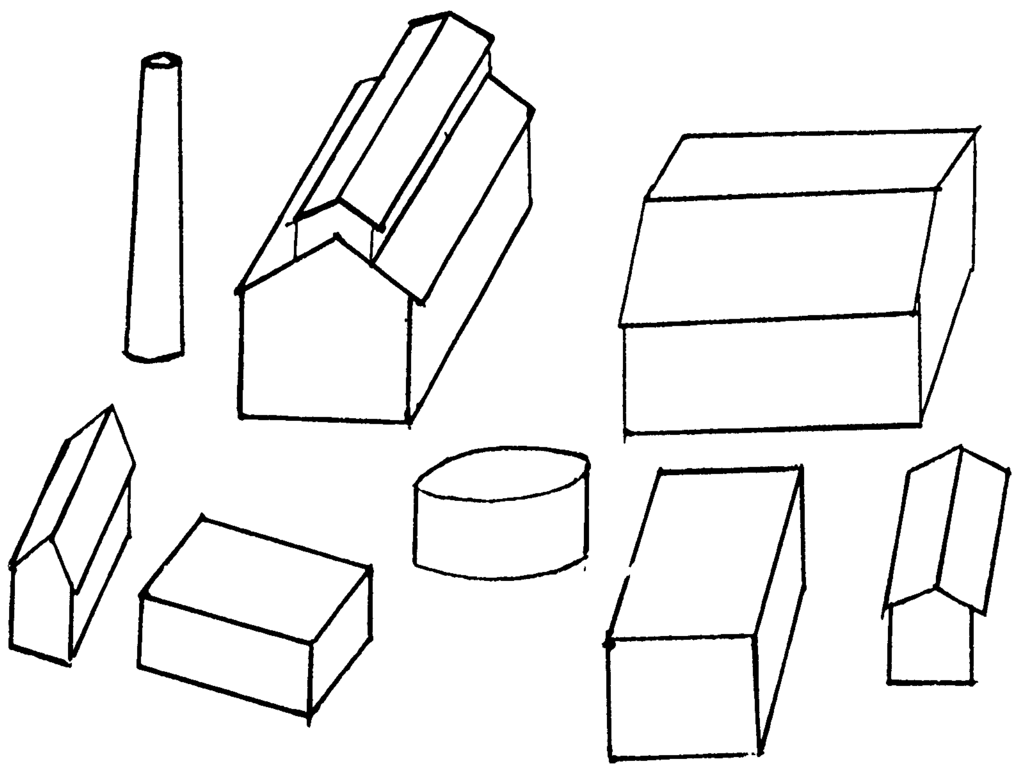


Figure 4. Synthetic Breakup With Generic Features

color of the texture might be varied as a function of feature ID and surface material category for features such as forests, oceans, plowed fields, or flat surfaces.

Manual intervention during CIG data base gaming area generation can be expected to remain an important procedure. Manual enhancements to the DMA DDB as well as manual creation of specific features not contained within the DMA DDB would be accomplished in essentially the same manner presently being employed for data base creation. However, due to the information content of the DMA DDB and the ability to use an automated transformation program for initial data base gaming area generation, the amount of effort required using manual techniques should be greatly reduced.

DMA DDB USE

The DMA DDB can be used as source data for CIG in a variety of ways depending upon the system requirements; e.g., size of the gaming area, training requirement, scene complexity, etc.

The most sophisticated method of data base generation would be to develop a transformation program, similar in concept to those presently being used for radar simulation which would transform the DMA DDB into a form directly useable by the CIG system. Of particular interest is the transformation of planimetry (culture and terrain). Both cultural and terrain features would first take advantage of basic descriptors such as geographic location and defining outline. Cultural features; e.g., buildings, bridges, towers, etc., could be enhanced during transformation by the insertion of generic models and representative colors to either ground truth or synthetic features. This would be accomplished as a function of the feature ID and surface material category. Additional enhancements such as texture or curved surface shading would then typically be added during processing. Landscape features; e.g., forests, lakes, rivers, fields, etc., would not usually require generic modeling but would require the assignment of a color. Similar to cultural features, texture and curved surface shading could also be added to landscape features during processing if necessary, also as a function of surface material category and feature ID.

Manual enhancements to the data base via an interactive CRT display using photographs or civil engineering drawings as additional source material would normally be made only as exceptions. However, the bulk of the data base, including the terrain elevation, would be transformed automatically in the described manner. This approach has the advantage of requiring minimal manual intervention during data base creation and of being capable of producing a large gaming area in a relatively short amount of time.

The most basic method of using the DMA DDB would be to use the digital elevation data contained within the terrain elevation file and the cultural manuscripts and listings as the basic source reference in a manner similar to the way a chart is used. Photographs, drawings, and additional high resolution charts would then provide any additional detail desired for manual data base creation. Even this method of using the DMA DDB has the advantage of providing a single source reference for reliable, current, and accurate data to be used as the initial starting place for CIG data base generation.

As would be expected, many other options can be defined which would fall in between the two described extremes. The training requirements for the CIG might dictate the approach to be taken. For example, if the required data base is relatively small and contains well known and visually significant cultural features, it might be desirable to use the DMA DDB only as the basic source reference and to put extensive effort into manual creation. If, on the other hand, a large data base containing cultural features of less importance is required, the automated transformation approach would be desirable. For a data base required to support a complete strategic or tactical scenario, the approach might be to employ automated transformation of both culture and terrain elevation for the entire data base, minimal manual enhancement for enroute navigational portions, and extensive manual enhancements in target areas. The potential for different approaches using the DMA DDB for CIG gaming areas is limited only by the creativity of those individuals who have undertaken the effort.

ADVANTAGES AND WEAKNESSES

Many advantages, as well as weaknesses, realized when using the DMA DDB as a ground truth source reference for CIG data base creation have been discussed up to this point. As more experience is gained using the DMA DDB and as the DDB itself is refined and improved, the list of advantages can be expected to grow and, hopefully, the list of weaknesses to decrease. The following is a summary of what is felt to be the advantages and weaknesses as they are presently understood.

a. Advantages

(1) Level I data base should be available for virtually complete coverage of Northern Hemisphere by 1985.

(2) Provides common source reference for the correlation of all simulated systems (radar, electro-optical, visual, avionics, threat environment).

(3) Provide a sufficient information density necessary as a start point for hand modeling and enhancement.

(4) Simplifies source data collection.

(5) Provides a current source of ground truth.

(6) Can be easily manipulated, updated, modified, and enhanced using both computer graphics, displays, and tools, and automated methods.

(7) Permits a virtually automatic transformation of data to an on-line format compatible to be developed for CIG systems within the limits of the data content and resolution.

(8) Provides a great deal of flexibility in use (terrain elevation file, planimetry file, manuscripts, data listing, etc).

b. Weaknesses

(1) Lengthy time period required to produce high resolution data.

(2) Does not contain the detail needed to model the world at all levels of perceptibility. In certain instances will require enhancement from other sources.

(3) Limited availability of required data base areas. (Present demand exceeds availability.)

SUMMARY

For any CIG system, a considerable effort must be expended to produce the data base describing the area to be simulated. Much of this effort involves the gathering of the ground truth source data and getting it into a useful form for simulation usage. The potential application of the DMA DDB as ground truth information for CIG systems has been demonstrated and steps are being taken to improve the universality of the DDB. It cannot be expected that the DMA DDB will, in the forseeable future, be adequate for being used as the exclusive source of data for CIG visual systems without further manual and/or automatic enhancements. However, it can be expected that the DDB will go a long way in meeting the basic requirements for CIG visual systems and, at the same time, greatly reduce the effort previously required to gather ground truth source data.

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INTELLIGENT-THERMAL-BASED GRAPHICAL
COMMUNICATION SYSTEM

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Education

Mr. FitzHenry received his B.S. in electrical engineering and computer science in 1970 and his M.S. in electrical engineering in 1971 from the University of Illinois at Urbana-Champaign.

Experience

Mr. FitzHenry joined the Aviation Research Laboratory of the University of Illinois in 1970 and, as a graduate research assistant, was responsible for integrating a Reytheon 704 digital computer with a Singer-Link GAT-2 general aviation synthetic flight trainer and for programming the computer to simulate area navigation computations for experimental computer-generated moving-map diplays and conventional symbolic/pictorial indicators. After receiving his Master's degree he received an appointment as a research associate, and in 1971 he was promoted to Head of the Simulation Group of the Aviation Research Laboratory.

Between 1972 and 1976 he was centrally involved in a research program titled "Computer-aided Decision Making for Flight Operations," a joint effort with the University's Coordinated Sciences Laboratory supported by the Air Force Avionics Laboratory to apply advanced "artificial intelligence" technology to real-time inflight decision making. Between 1974 and 1976 he served as co-principal investigator with Professor Robert Chien on this program and concurrently was responsible for simulation and flight performance measurement developments in support of Contract N00014-76-C-0081, titled "Advanced Aircraft Displays and Augmented Flight Control" for the Office of Naval Research.

Mr. FitzHenry earned his Private Pilot's certificate at the Institute of Aviation with the support of a flight fellowship from the Link Foundation.

Awards and Affiliations

Tau Beta Pi, Eta Kappa Nu, Engineer in Training.

Roger L. Johnson

(Photograph and Biographical Sketch-not available)

INTELLIGENT-TERMINAL-BASED GRAPHICAL COMMUNICATION SYSTEMS

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University of Illinois at Urbana-Champaign

Abstract

A current problem facing the defense, scientific and general professional communities is the management, distribution, and access to an expanding accumulation of alphanumeric and graphic information. This problem subdivides into four interrelated problems of generation, storage, transmission, and presentation. Present research and development activities have focused considerable resources upon the storage and transmission aspect of the problem. It is our contention that powerful, personalized, intelligent terminals can reduce the current mismatch between the world-wide military data processing and communication facilities and the military user by the graphic presentation of information with auditory overlay.

Background

Pieces of the electronic graphic mail concept have been proposed and implemented over the last ten years. The collection of these pieces and the incorporation of advances made in related fields to make an integrated information service have not yet been done. The general shortfalls we perceive in existing electronic mail systems are in the following areas:

1. High communication costs,
2. Low graphic with audio-overlay support,
3. Little real-time interactive capability,
4. Negligible emphasis on human factor in system design.

A brief review of past and present electronic mail systems will demonstrate these shortfalls. A proposed solution, based on a distributed network of intelligent terminals follows the review.

The Picturephone experiment conducted by the Bell System is probably the largest effort to date in interactive graphic/audio communication. Although it was a failure economically, deeper insights into the limitations of two-way video service are available as a result of the experiment. Cutler (1975) summarized them as follows:

1. It is not much use until nearly everyone else has one. I can't think of anything but the telephone that has that characteristic.
2. It requires an enormous investment in interconnection facilities to make it useful.
3. It must provide a really useful service, not otherwise conveniently available.
4. Its usefulness is a learned skill, and requires development of new habits of behavior.

Facsimile systems are currently the only commonly available means of electronic graphic communication in moderate (4 minutes per page) amounts of time. While the cost of a facsimile unit is fairly reasonable (under $5000), it is expensive in time and communication cost. And, it cannot be used in interactive environments where images appear in seconds with audio overlays. The technology used in facsimile is compatible with techniques recently developed at the University of Illinois in image compression, error correction, and the incorporation of video images into man-machine systems (White, 1975; Judice, 1974).

The United States Postal Service and various commercial service agencies are developing or have operational electronic mail systems. The approach is to have a "store and forward" network for alphanumeric messages. There is not emphasis on graphic, audio, or interactive capabilities. These agencies are dealing with concepts such as data compression, storage and transmission, and the security and privacy issues, which are real problems for any electronic mail system.

Throughout the last several years a protocol has evolved on the ARPANET for the transfer of personal messages or "mail" over the network. This protocol defines only the transmitted form of the message, not the nature of the human interface. Two major installations, those of Bolt, Beranek, and Newman, Inc., and Information Sciences Institute, use the same mail protocol and have become centers for this activity. The services are also available at several other nodes on the ARPANET having similar hardware.

In addition to personal mail, the ARPANET also offers a forum or group mail file. With this, messages are sent to a general file and are read by many users. This provides a medium for group interaction usually on a single topic. These files have a tendency quickly to become too large and disorganized for easy perusal.

ARPANET mail currently is limited to an alphanumeric format. The University of Illinois has demonstrated the feasibility of graphic mail by using intelligent terminals. The intelligent terminals code graphic commands into character codes at the transmitting site, and the receiving intelligent terminal decodes the commands for presentation on a graphic display. There is work underway in ARPA to create a new graphic protocol.

In the mid 1960s, Bitzer and his associates at the University of Illinois proposed a large-scale experiment in computer-based education (Bitzer, 1968). The proposed system, called PLATO, has become one of the most advanced visual communication systems in operation. In addition to its primary task of computer-assisted instruction, PLATO supports a spectrum of electronic mail services and rudimentary forms of graphical teleconferencing. Unlike the ARPANET, PLATO is a highly centralized system. This has implications for degraded-mode operations, security, and communication costs to remote sites. Like the ARPANET, PLATO's mail format is basically alphanumeric.

Closely related to electronic mail is the concept of the electronic office. The electronic office integrates facsimile, local copying, word processing, and computer access into a single system. Large-scale research and development efforts are currently underway in this area by the office equipment vendors such as IBM, Xerox, and 3 M. The projected release of these systems is in the early 1980s. The electronic office depends heavily on graphic electronic mail. Emphasis should be placed on having the electronic office integrated with the concepts of computer-based graphics, interactive-communication, and management-information systems.

Proposed Solution

We believe that a solution to the problem of creating an effective electronic mail system is through a network of powerful personalized communication terminals with graphic displays. The proposed system consists of three components. They are illustrated in Figure 1 and listed below:

1. Personal computers with touch-sensitive graphic and audio displays, and local mass storage.
2. A site controller with resources such as large mass storage, group-level library, message switching, and hardcopy-to-electronic/electronic-to-hardcopy mail conversion capability.
3. An interface to allow access to existing communication networks, data services, and other remote-site controllers. (See Figure 2 for a representative interconnection using the ARPANET.)

This system design directly overcomes the previously mentioned shortfalls in the following manner. High communication costs are lowered by sending information as encoded commands rather than raw data. This reduces the number of bits required to describe a page and thereby decreases the transmission time for a page. Major encoding is done using distributed computing power to allow the user to create graphics at the terminal rather than go from paper to electronic signals (facsimile). If facsimile must be used, the electronic image is encoded as much as possible at the local site via image compression before transmission.

Audio is converted to computer format at the local site and compressed before transmission. Since transmission time is minimized, the ability to carry on interactive dialogue is enhanced. The ability to make the terminal user-orientated is now possible given the man-machine interfaces (touch sensitive screen and graphic display) and large local processing power and computer storage. The intelligent terminal will be able to prompt the user in English, provide help sequences, and in general guide the computer-naive-user by the hand through the intricate and varied possibilities available to him in the electronic graphic mail system.

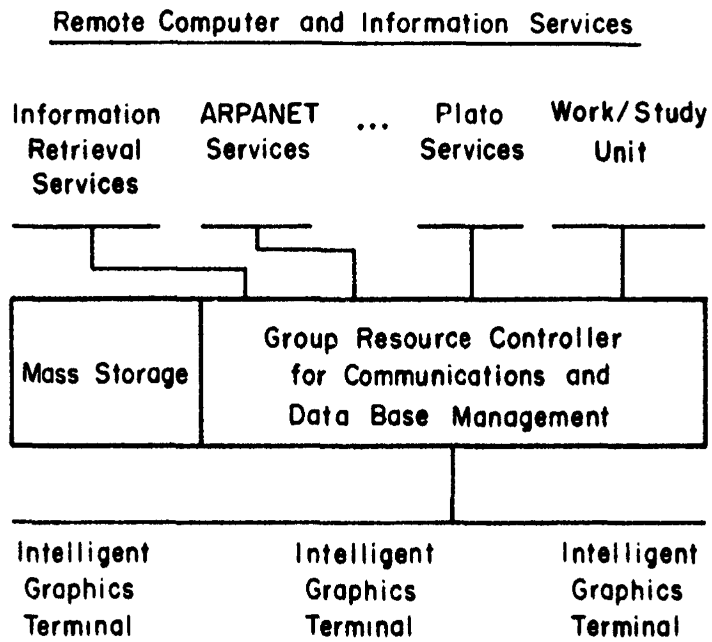

Figure 1. Graphic Communication Network Professional Work/Study Unit

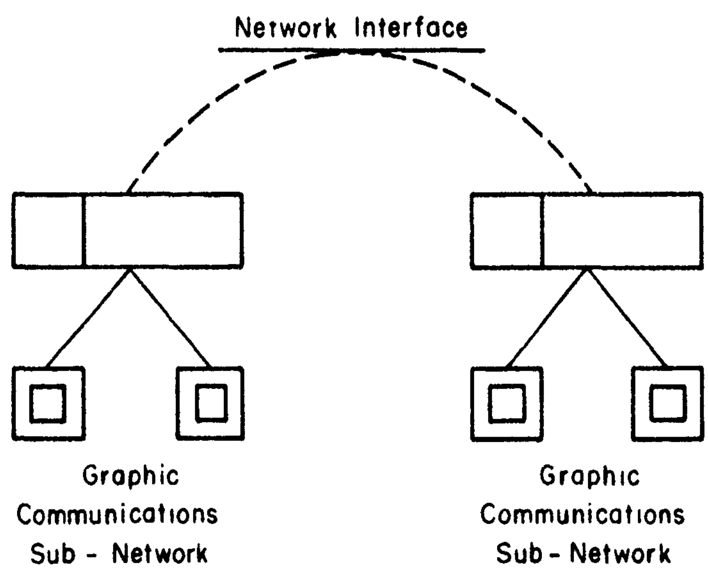

Figure 2. Block Diagram of a Two Group Graphic Mail System

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ILLUSION, DISTANCE, AND OBJECT
IN
COMPUTER-GENERATED DISPLAYS

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Malcolm L. Ritchie has been Professor of Engineering at Wright State University since 1969 and President of Ritchie Inc. since 1957. He has published research in aircraft and spacecraft control-display, in automobile driver information processing, in the perceptual problems of computer-generated displays, and the nature of the engineering design process. He has been a consultant on a number of aircraft, spacecraft, and simulator programs, and has been a regular control-display consultant in the appliance field.

ILLUSION, DISTANCE, AND OBJECT IN COMPUTER-GENERATED DISPLAYS

Malcolm L. Ritchie
Wright State University

I noted with interest that Barry Goldwater was on the program yesterday, and I am sorry I missed him. 35 years ago today I was a cadet at Luke Field and Captain Goldwater was one of my ground school instructors. I wish I had been here yesterday so I could have asked him what he has been doing since 1942.

I spent something like 1500 hours as a B25 flight instructor in the first half of World War II. I made copious mental notes about the information processing of my students - particularly in their sensing of motion as they learned and then mastered flight by instruments. In later years those observations led to experiments on "instruments-first" flight training (1, 2), and also to the automobile driving experiments in which we measured lateral acceleration (3, 4).

I spent the last half of World War II as a Night Fighter pilot in the Pacific. There I developed a practice of never using landing lights for landing. I used the runway outline lights only as the information for breaking glide and making contact. Once learned, this information was more dependable than using the variety of surfaces and textures which comprised our strips. And then, you could land without calling attention to yourself, as I had to do once with fuel spent and enemy strafing planes all around.

This landing technique was like the one produced at Illinois in the early 1950's with a Link-crab-mounted runway cutout moving against a point source of light. It can be reproduced today with a computer-generated visual display showing only a runway, and perhaps a horizon.

We had a good radar set in the P61 with which my radar observer and I used to practice low approaches to the runway. He would set the radar up so I had a good picture of the runway and the surrounding jungle on my 2" by 3" scope. As I flew instruments guided by the view of the runway, he called out range and altitude. We practiced enough with that radar view that we decided we would land zero-zero if we ever had to choose to do that or bail out. (Incidentally both of us later earned Ph. D.'s.)

I had done those things plus some theoretical analyses of the information used in flying tasks (5) before I got called into the picture-drawing computer business. When John Shinn and Mel Johnson of General Electric began teaching me about computer-generated visuals for flight simulation, they first had me get in and fly the simulated A4 at Kingsville. I made a number of landings on the Kingsville data base and on a Lexington-class carrier, then flew formation for about an hour. A lot of what I saw looked like things I had seen before.

After I had grappled with the CGI beast at first hand they told me all the problems of the acceptance of the machine in that setting and we began to work out a cure for as many as we could. I think we did pretty well (6).

Some of the things we did to human engineer the Kingsville system were things that may be difficult or impossible to account for if you only consider the picture. Considering the pilot's task, his information processing, and his perceptual characteristics sometimes get you into areas that are not very predictable in other terms.

Figure 1 shows a view of a Lexington-class carrier as it had been prepared from blueprints and color photographs. Notice the dark-colored landing area delineated by white marks about a foot wide. When seen at a distance of one mile through the resolution of the raster scan display, these one-foot wide markings just could not be used to line up an approach.

We repainted the deck of the carrier as shown in Figure 2. The black deck we made white and the foot-wide lines became light gray. The lines could only be seen for the last few hundred feet. From a mile out you could now line up with the large white rectangle.

Probably no real carrier ever looked like this. To casual observers we may have seemed to be distorting reality. But to our Navy pilots the visual display was now useful without any change in resolution. Not only did we not get any complaints about our color scheme, one of our Navy pilot-engineers went us one better. When he learned to control the computer he chose an alternate color scheme. His landing area was a dull red.

One of the complaints about the early Kingsville system was that the horizon was too high. Very early I suspected that we had a genuine illusion involved and I am now convinced that such was the case. The digital computer, of course, locates things very accurately. I did a short experiment at Kingsville to demonstrate that with only the visuals and without their flight instruments, the Navy pilots were pretty crude in their ability to find out where the horizon really belonged.

We cured the horizon height illusion by putting in aerial perspective. Figure 3 shows the kind of scene you get when there is an increasing amount of atmosphere between eye and surface as the distance increases. In Figure 4 you may see the illusion. With no atmospheric attenuation the computer will render the color assignment very faithfully and it will be exactly the same right up to the point at which surface ends and sky begins. That, I believe, is what caused the illusion.

Illusions may at times be pesky, frivolous, or deadly. They can be diffi-

cult to predict and easy to design into. When they occur the effects can be remarkably consistent across a wide spectrum of observers, but difficult to relate to the dimensions of the stimulus. Figure 5 shows the Muller-Lyer illusion. This one has been studied by a host of experimental psychologists. The effect of the tails on the perceived length of the line has been related to the length of the tails, their angle to the line, the area enclosed, and perhaps numerous other things. None of them can quite precisely predict the illusory effects of this quite simple figure.

There is a strong tendency in the human perceptual system to see objects. If it is at all possible the visual field will be organized instantly into objects and background. Figure 6 shows a demonstration of this principle. Ames (7) had three different assemblages of objects in a box. When seen from the controlled viewing window each assemblage was immediately seen as a chair. The picture shows that two of them looked very different when seen from other angles, one being a group of elements not even connected to each other.

This tendency to see objects accounts for the perceptual phenomenon which psychologists call "size constancy". We ten to see a car as a car through a wide range of distances and are not even aware of the size of the visual angle it subtends in our field of view. The classical picture of the artist holding brush handle at arm's length and measuring the size of the image for his painting, shows that even the person trained in perspective cannot readily overcome the size constancy effect.

The tendency to resolve a scene into objects can be illustrated in quite another way. Figure 7 shows Picasso's "Woman with a fish hat". Nearly everyone who looks at this picture will try to see a face with the eyes, nose, and mouth in the customary positions for a face. They are not in those positions, so they can't be resolved into an ordinary face. But the perceiver is unable to deal with the picture any other way. He remains in a state of perceptual conflict. It was undoubtedly the purpose of this painting to produce this sensation of conflict.

Metelli (8) has written a nice article describing the transparency illusion as shown in Figure 8. He describes a relatively simple mathmatical relationship to describe the conditions under which these adjacent figures will be seen as transparent and continuing over other bodies of different colors. The transparency illusion, though thus simply accounted for, is analyzed after the fact. It will be quite a different matter for a data base designer to predict before hand when these conditions will be satisfied at given viewing angles and distances.

Figure 9 shows an artist's example of the degrees of shading which describe a curved surface. This is a straightforward relationship and one which can readily be reduced to computer calculations. But many of the other tools in the trade of the painter are much more difficult to regularize.

Figure 10 shows an illustration used by Gombrich (9) to discuss the problem of going from stimulus to perception in the synthesis of pictures. He relates charmingly how his teacher in Vienna drew a circle on the blackboard which any Vienese boy could immediately identify as a loaf of bread. With the addition of an arc he and his fellow students immediately recognized a shopping bag. The addition of two little marks on top now made it into a purse. And finally a curved line for a tail changed the picture into a cat. Writing many years after the demonstration the recalled the wonder at the realization that each succeeding object destroyed all former objects. Though he knew the picture of the purse, the shipping bag, and the loaf of bread were all in the picture of the cat, he could only see the cat.

While it may be news to some in this audience it has long been recognized among painters that even the color of objects often depends more on the eye than on the stimulus. Figure 11 shows clearly that a given color can be regularly seen as a different color depending upon what else is shown near it.

Painters talk about "creating space" in their paintings. What I think they mean by this is that they do those things required to bring the third dimension into the flat canvas. In Dali's "Crucifixion" (Figure 12) it is immediately obvious that the artist is the master of the creation of space. Even in a strange and unusual scene one has very little doubt about the intended position in space of everything the painter has put in place. Dali is well known for creating strange spaces, but it should be clear that his ability to do that depends upon his being able to put things in whatever space he wishes.

It is widely agreed that photography as an art form has greatly diminished the art of representational painting - the painting of objects. In a very real sense the engineering of picture-drawing computers is in the process of bringing back that art. And art it is. For the synthesis of pictures for predictable perception holds many a surprise yet for data base designers.

An artist who can choose his subject and his lighting conditions can produce very realistic objects.In Figure 13 Caravaggio used strong contrasts and shadings to make his figures stand forth. One of the most famous painters of people was Ingres, whose "The source" (Figure 14) shows a life-like figure which many think has hardly been equalled for object quality. Ingres is famous for what he could do with a line. Now lines may be soft or hard or many gradations between, and what happens to the perceived object is greatly affected by what the painter does with his lines. The troubling thought for many of us in this room ought to be how much of all the techniques of the painters we will have to learn to build our pictures predictably. Will we be able to do as well as Dali (Figure 15) in locating and describing our objects in space?

Let me describe an intriguing and troublesome experiment. Ryan and Schwartz (10) asked their subjects to report the orientation of a hand which was depicted in four different ways: a. a black and white photograph, b. a shaded drawing, c. a line drawing, and d. a cartoon-type simplified drawing. The subjects could make that response quickest and most accurately with the cartoon-type simplified drawing. Let me leave you with the thought that sometimes we may get the most useful picture by deliberately departing from fidelity in perhaps many yet-to-be-determined ways.

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A part of the work reported here was supported by the Aerospace Medical Research Laboratories of the USAF.

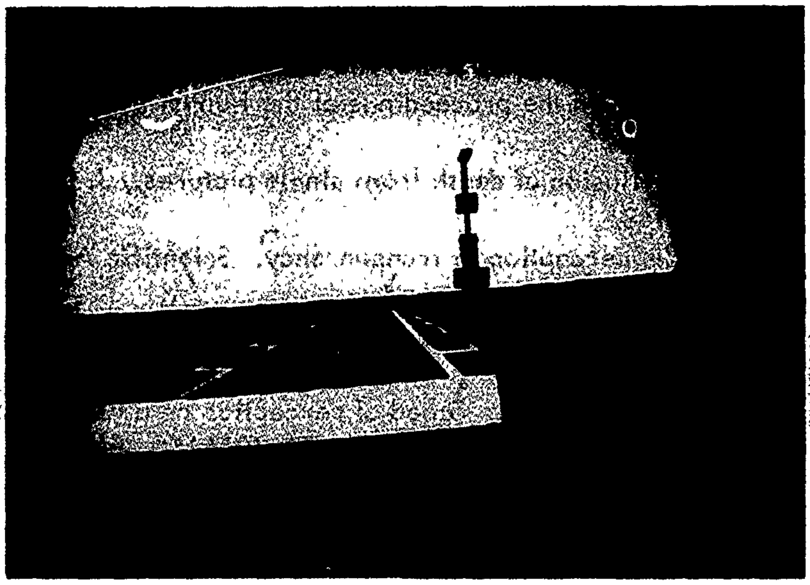


Figure 1

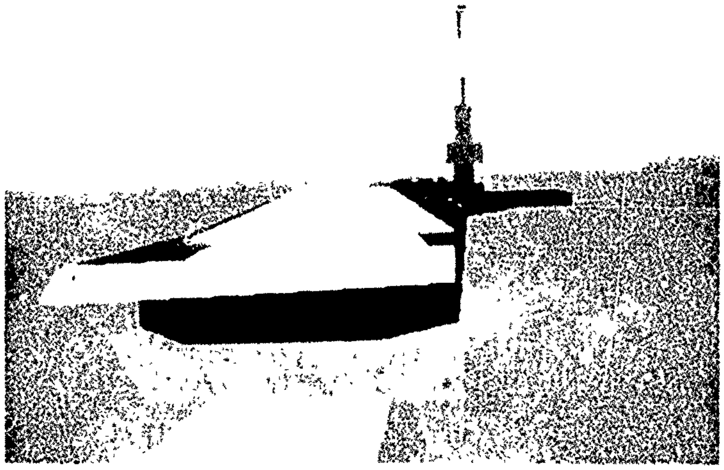


Figure 2

Figure 3

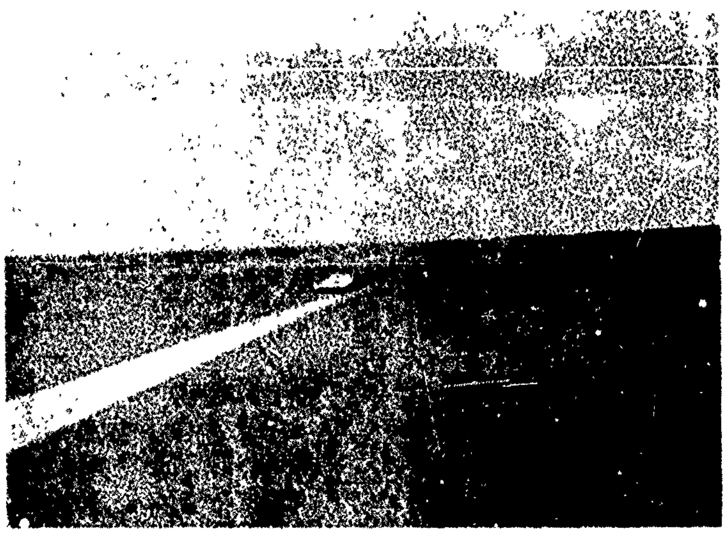
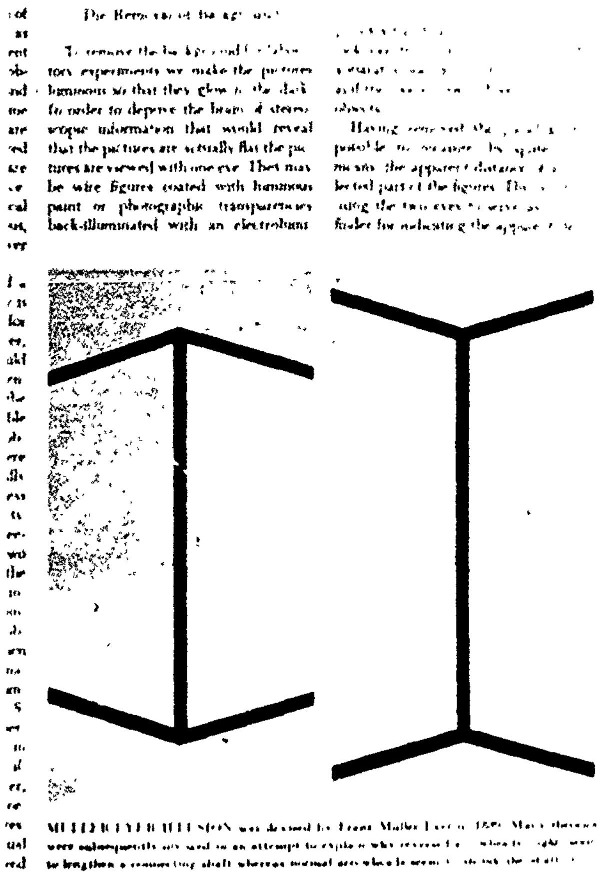


Figure 4



To remove the background [illegible] laboratory experiments we make the pictures luminous so that they glow in the dark. In order to deprive the brain of stereoscopic information that would reveal that the pictures are actually flat the pictures are viewed with one eye. They may be wire figures coated with luminous paint or photographic transparencies back-illuminated with an electroluminescent [illegible]

Having [illegible] possible to measure, by [illegible] means, the apparent distance [illegible] lected parts of the figures. [illegible] using the two eyes to serve as [illegible] finder for indicating the apparent [illegible]

Figure 5

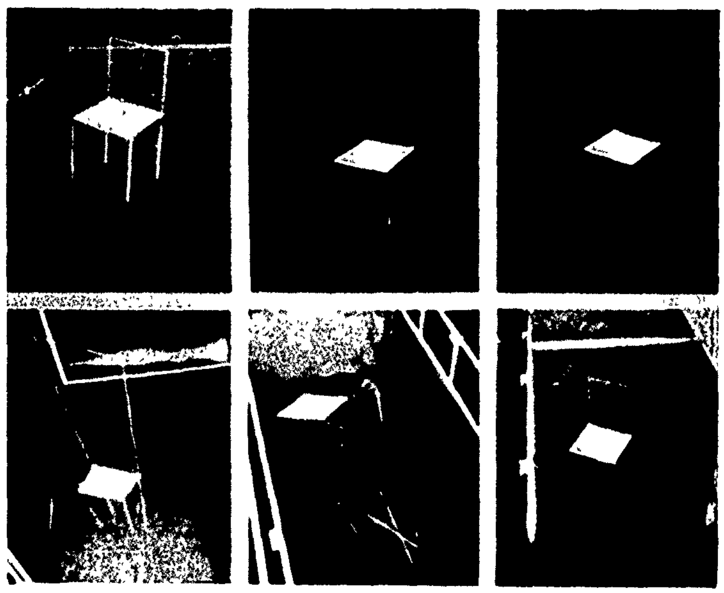


Figure 6

Figure 7

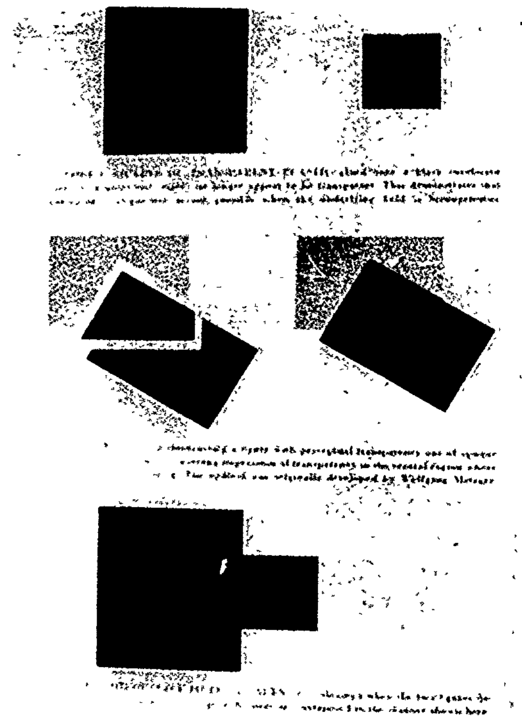


Figure 8

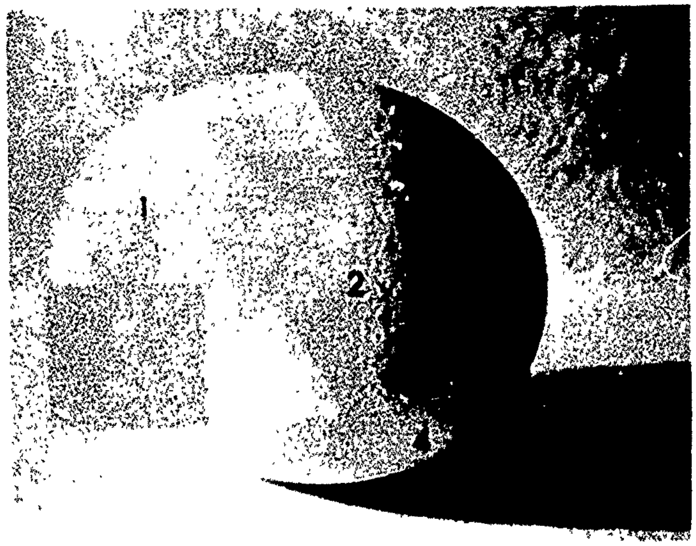
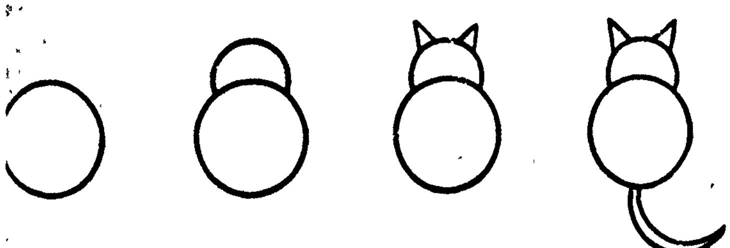


Figure 9

little squiggles on its ... would make it shrink into a purse; ...
by adding a tail, here was a cat [3]. What intrigued me, as I lear



3 *How to draw a cat*

trick, was the power of metamorphosis: the tail destroyed the p
created the cat; you cannot see the one without obliterating the ot
as we are from completely understanding this process, how can
e to approach Velázquez?

Figure 10

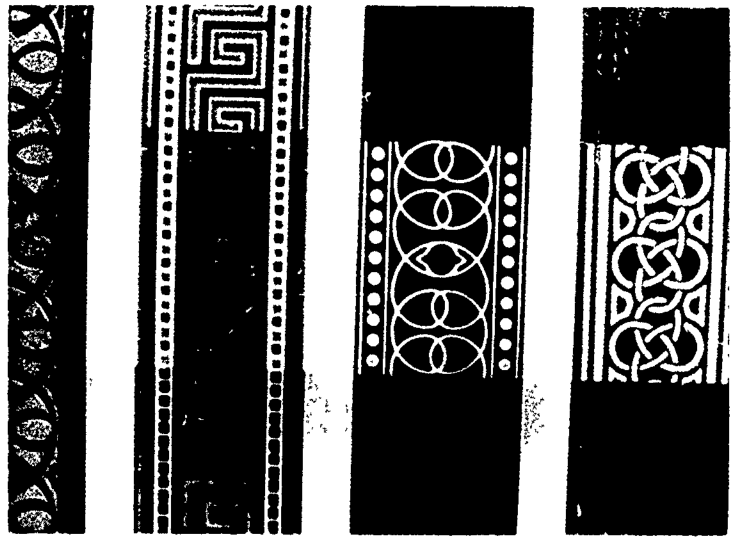


Figure 11

Figure 12

Figure 13

Figure 14

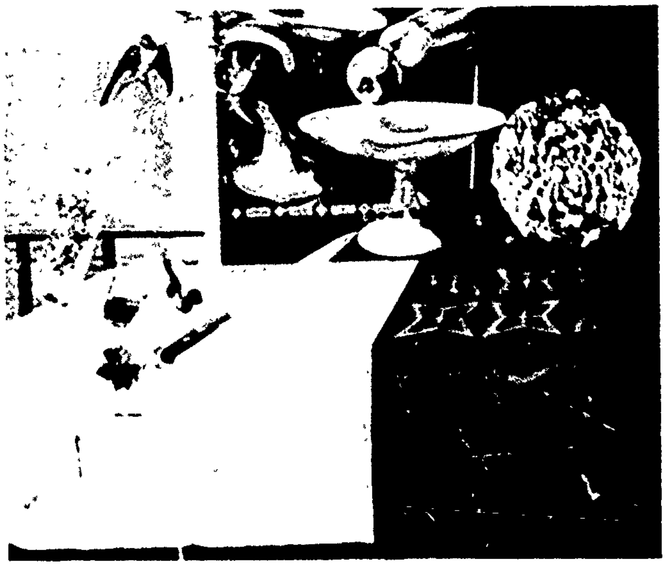


Figure 15

Figure 16

SESSION V

Chairman
James E. Brown
Research Psychologist
United States Air Force Tactical Air Wartare Center
Eglin Air Force Base, Florida

James E. Brown

Mr. James E. Brown is an Engineering Psychologist working for the United States Air Force Tactical Air Warfare Center, Eglin Air Force Base, Florida. He presently serves as technical advisor to the Deputy Chief of Staff, Aircrew Training Devices (USAFTAWC/TN). His organization has responsibility for acquisition, modification, and test of aircrew training devices within the Tactical Air Command (TAC). He received a Master of Science degree in Industrial Psychology from North Carolina State University in 1962. Jim has over 18 years' experience in human factors and flying training research. Prior to joining USAFTAWC in 1976, he served as a research psychologist for six years in the Air Force Human Resources Laboratory, Flying Training Division (AFHRL/FT), Williams Air Force Base, Arizona, and was employed in the aerospace industry for eleven years. He has served as principle investigator and program manager for flight simulation and flying training research programs in industry and government. Since his employment by the Air Force, he has worked on development, test, and evaluation of fighter aircrew training devices, improved visual systems for tactical aircrew training, Instructional Systems Development (ISD) programs, future Undergraduate Pilot Training programs, adaptive flight training systems for fighter weapons systems, and performance measurement development. He was instrumental in the establishment of the AFHRL operating location at Luke Air Force Base, Arizona, to perform Tactical Aircrew Research in support of TAC. Jim has authored more than 35 professional articles, research reports, and presentations.

IMAGE QUALITY: A COMPARISON OF NIGHT/DUSK
AND DAY/NIGHT CGI SYSTEMS

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Mr. Schumacker is responsible for product planning and development activities associated with CGI visual systems. He has been associated with the development of CGI systems since 1963.

Mr. Schumacker joined Evans & Sutherland in 1972 and was directly involved in the conception and implementation of the first NOVOVIEW product. Since then he has contributed to system architecture and algorithm development for a series of image generation systems. Mr. Schumacker received his Master of Science degree in Electrical Engineering from the Massachusetts Institute of Technology in 1960.

Rodney S. Rougelot
Vice President & Manager
Simulation Systems
Evans & Sutherland Computer Corp.
Salt Lake City, Utah 84108
(Photograph not available)

Mr. Rougelot is presently responsible for all CGI programs at Evans & Sutherland. Since joining the company in 1972, he has been associated in various capacities with the NOVOVIEW product line as well as day/night image generator programs for CAORF, NASA-JSC, and Lufthansa.

Mr. Rougelot was employed at General Electric in Ithaca and Syracuse, New York, from 1960 through 1972, where he worked on such programs as the NASA I, NASA II, and NASA III and RGS-128 CGI Systems and was associated with the early development of the Genegraphics product.

Mr. Rougelot received his B.E.E. degree with high honors from Cornell University in 1956. He is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi, and the IEEE.

IMAGE QUALITY: A COMPARISON OF NIGHT/DUSK AND DAY/NIGHT CGI SYSTEMS

R. A. SCHUMACKER and R. S. ROUGELOT
Evans & Sutherland Computer Corporation

Introduction

Computer generated images are now generally accepted as a means of simulating out-the-window scenes for pilot training. Today there are well over 120 CGI visual systems installed and operating throughout the world. Five years ago there were less than five systems and these were in engineering rather than training applications. Although the vast majority of systems in the field today are of the NOVOVIEW night/dusk class (Figure 1), it is significant that day/night systems (Figure 2) have now achieved performance which has stirred widespread interest in the simulation field. Major strides are being made in both types of systems at an increasing pace.

Daylight CGI technology dates back almost fifteen years. A relative newcomer, the night system, originally based on general purpose graphics technology, has developed rapidly in less than four years into highly specialized equipments. The night/dusk systems have undoubtedly been influenced by daylight technology but they retain a quite different approach to image generation which is the basis for their relative simplicity and low cost.

Why are there now two viable approaches where a short time ago CGI was merely a curiosity? There are many factors, most of which are beyond the scope of this paper. But to a large extent these factors are rooted in issues of image quality. Image quality is an interesting discriminant because the two approaches are fundamentally quite different in this regard and scene fidelity is a paramount concern in visual simulation. We will look at the basic differences between night/dusk and daylight technology from the standpoint of image quality, relate these factors to the evolution of present systems, and describe some recent developments in image quality improvements.

Relationship of CGI Systems

CGI systems can be classified within the framework shown in Figure 3. The different approaches are distinguished by the display technique employed. Day/night systems are characterized by their exclusive use of a raster scan to display the entire scene content. We will see later how this property is at once responsible for its potential for complex scenes as well as the source of problems which have been frustratingly difficult to overcome.

The various night/dusk systems which exist occupy positions under the calligraphic and hybrid headings. The common characteristic of these systems is that the pictures are drawn in a feature sequential manner rather than assembled in parallel for output in raster scan format. Calligraphic displays are capable of drawing light points and line segments and have been the mainstay of line drawing graphics systems. Solid surfaces have been rendered by filling in additional lines in the surface model but this has not been very useful in simulation because such lines tend to converge or diverge when viewed in perspective.

As solid surfaces such as runways and markings were introduced into night/dusk systems the approaches clustered under the hybrid category. In all cases lights are drawn as individual points generally in their order of computation. The mini-raster approach to surfaces is an extension of this philosophy wherein each individual surface is painted by a small raster sized to fit the desired perspective image. The NOVOVIEW approach retains the daylight notion of parallelism by scanning a single raster structure appropriately sized to include all areas of the display which contain surfaces. This of course can include the entire display for some requirements. It is important to note, however, that the calligraphic display technique permits this raster to assume different orientations and resolution quite easily -- a flexibility not found in conventional television displays.

Display Techniques

We have already separated the night/dusk and day/night systems on the basis of display techniques. Let us examine some of the implications of the display devices and scan methods on image quality.

The night/dusk systems employ beam penetration displays. The beam penetration CRT has the inherent high resolution properties of a black and white CRT but provides color capability. Its two-color phosphor provides a spectrum between red and green including a yellow-white. These colors are well suited to the night/dusk application but the absence of a blue component is a serious drawback in representing daylight illumination conditions. Because the various colors are obtained by changing the energy of its electron beam, rather than adding contributions of several beams of different color, the colors produced are free from convergence problems that result in color fringing. White brightness of beam penetration CRT's has lagged that obtainable on full color devices by a factor of three or four. Although it is possible to increase the brightness this has not been practical because persistence characteristics result in image smear.

The feature sequential scan used by the night systems means that light points, individual surfaces, or groups of surfaces can be displayed as they are computed -- greatly simplifying the image generating hardware. Night systems are typically one rack including the general purpose computer versus about ten for daylight systems (of course there are scene content differences too). The content of night/dusk scenes has been influenced principally by limitations in display drawing speed. Although steps have been taken to increase the parallelism in the display of surfaces the basic approach considering both lights and surfaces is still sequential and drawing time requirements increase with scene complexity.

The day/night systems generally drive full color displays based on the shadow mask CRT, or the various color projection devices. In all cases the resolution is substantially lower than that obtainable from penetration CRT's because of physical structures within the device, spot size, or the inability to support faster scan rates. In addition, color convergence, color fringing, and color separation problems are introduced. Although higher brightness is always sought, levels adequate for daylight scenes are achievable.

The raster format employed by day/night systems permits the parallel assembly of very complex scene information to occur uncoupled from the raster scanning process. It is the conversion of scene data into raster format that

accounts for most of the bulk and complexity of this system's hardware. Scene complexity is not limited by the speed of the display but by the capability of the hardware that can be focused on the image generation task.

Resolution

The resolution differences between a NOVOVIEW and a day/night system operating at 625 line television standards are illustrated in Figure 4. The relative scale assumes identical size CRT displays for the two systems. There are two aspects to resolution important particularly in the display of small objects such as lights. These are the positional resolution (the least amount by which we can move a spot) and the size of the spot itself. Calligraphic displays can achieve positional resolution equal to a fraction of a spot diameter. Spot motion with no discernible discrete steps can be achieved. The spot size for typical scene lights can approach 1/2000 of a display width. This translates to less than 1.5 arc-minutes in typical visual system use.

The raster structure, by comparison, is quite large. Spot size is usually not limiting and is generally made large enough to reduce the appearance of raster structure. The analog of positional resolution here is not as obvious. One interpretation would be the pixel dimension, but this is not quite correct. If we were to represent a light point by a single pixel, it could indeed move only by multiples of the pixel dimensions. As this would result in objectionable discrete movement, the general approach is to spread the light image over adjacent pixels in a manner which improves the apparent motion smoothness. The broader the image the smoother its motion can appear. However, a compromise is required because the effective size of the point has also increased. A reasonable trade-off here might result in an apparent minimum light size as indicated by the circle shown within the raster. We would have to decrease the raster size by about a factor of four to match the performance of the calligraphic display.

Night/Dusk Systems

The "world" of night/dusk simulation typically consists of lights, gross terrain and cultural features with low detail and low contrast, and rather concentrated areas at airports where faithful rendition of detail is important. The scope of this problem is quite modest when compared to the ambitious goals of daylight simulation. The night/dusk systems can aim to approach the real world. Certainly there are many more lights in a large metropolitan area than can actually be shown, but sufficient lights are available to represent the relative densities of lights in a useful way.

Perhaps most important is the fact that the scene elements that are displayed behave very much like their real-world counterparts with very few artifacts to betray their computed origin. Although achieving a high quality visual system of this type is not trivial, its development did not have to contend with fundamental display limitations.

Partly because high quality images and useful scene content were achieved in early product versions, we find that subsequent system development focused not only on increased scene content but also on providing subtle refinements in the visual cues. Examples include:

- Landing Light Lobes -- curved patterns can be configured for different aircraft and various combinations of lights activated by the pilot.

- Low Visibility Effects -- including atmospheric glare due to environment and aircraft lights, and light halos.

- Light Directionality Patterns -- various pattern shapes and widths can be assigned to lights; attenuation is computed based on azimuth angle to individual lights.

- Curved Light Strings -- efficiently represent certain features.

- Special Effects -- such as bright strobes, flares, lead-in lights, etc. Flexibility of the calligraphic writing technique allows increased beam dwell for high brightness effects and manipulation of beam focus.

It is interesting to note that in a number of instances night/dusk visuals have introduced features that have later found their way into day/night systems. Field rate update is one example. Updating the image at rates slower than the refresh rate results in a double image effect which was quite bothersome on the first night systems produced in 1973. This was remedied by going to field rate update. This same problem was hardly noticed for a long time in daylight systems because it was masked by more serious raster-related defects. A sensitivity to this problem has developed only recently and a few daylight systems now incorporate field rate update.

The scene complexity and illumination effects provided by daylight systems have whetted the appetite of users and stimulated the imagination of night/dusk system designers. This has had the beneficial effect of accelerating development, but some caution is needed. Image quality issues should not be ignored in the zeal for more scene quantity and a "lighter dusk".

Night/dusk systems are now capable of displaying more surfaces than the early daylight systems. In addition to their light capability they can handle three-dimensional features, moving objects, and illumination effects; data base management techniques extend the useful gaming area; and an entire seven channel image generator can be housed in two racks. So far, image quality factors have not been a formidable barrier in the development of these systems.

Day/Night Systems -- The Aliasing Problem

Quite the opposite is true for daylight systems. Not only do they have the ambitious goal of simulating portions of the real world under the full gamut of illumination conditions, but they are saddled with the necessity to use a raster -- a discrete structure that is imposed on an otherwise continuous scene. After the initial exuberance over the ability to use a computer to produce solid shaded surfaces, the existence of raster-related problems was acknowled. The full implications were slow to emerge and may not

be fully realized even today. The problems were identified by symptoms such as jaggies, rastering, stepping, and scintillation -- and the remedies are often more numerous than the names. The general problem under consideration is called "aliasing", a term which covers a multitude of effects which arise due to quantizing and sampling at various stages during the processing and display of digital television images.

Until 1973 daylight systems in the field were producing pictures of surfaces with edges that appeared as a series of steps as shown in Figure 5. The steps appeared because each pixel was assigned a color/intensity value based entirely on a single sample of the scene taken at the center of the element. The solutions to this problem were termed edge smoothing, and sometimes qualified by the term "vertical" or "horizontal" according to the slope of the edge and its associated fix. An effective solution to this problem is to display each pixel which is cut by an edge as a blend of the colors within it, the percentage of each weighted in accordance with the involved areas. A reasonable approximation to such a weighting for a long, near-horizontal edge is to create a linear transition from one color to the next which extends over the requisite number of elements. Near-vertical edges result in a one-element transition. The addition of edge smoothing made a dramatic improvement in the appearance of the picture. It also exposed further problems to be solved.

Figure 6 shows some additional effects which result from quantizing vertices to the raster line boundaries. This strategy was employed, not because it was hard to compute a vertex properly, but because the scan line oriented processing could not handle edges that started or stopped in the middle of a line. The images looked quite good under static conditions but movement of the scene was accompanied by erratic behavior of the edges as vertex points independently shifted from one pixel to another. A partial resolution to this "edge walk" problem can be achieved by accurately determining the intersection of an edge with the set of interior raster lines and computing the proper smoothing transitions for these lines. The corners of the polygon will still cause problems because they form complex regions defined by two or more edges which meet somewhere in the middle of the scan line. A solution is to find representative area weights for the regions in the vicinity of each vertex. Reasonable approximations to the weighting can be

attained by substitution of appropriately shaped surrogate regions which span the full raster line. This can be done so as to achieve a consistent handling of adjoining polygons. A related problem occurs when an edge is actually horizontal. Here other means must be employed to avoid the appearance of vertical stepping.

The trend becomes apparent when we examine Figure 7 which shows several other more complex situations involving small detail. Special case solutions abound but they are only approximations based on limited data, such as intersect points and edges slopes, obtained along the sample line shown. It is not difficult to find situations where these methods break down simply because there is not enough information available on the single sample line to solve the problem.

DLH Day/Night CGI System

It was at about this point in the solution of aliasing problems that we embarked on a program with Redifon, in 1975, to supply a day/night visual system to Lufthansa Airlines (DLH). Their overriding concern was that the images be of the highest quality. Capacity was important but definitely secondary. The visual was to provide scenes for two independent and simultaneous cockpit simulations. It would be integrated into their existing complex consisting of four cockpits and two rigid-model visual systems, and would serve any two of the cockpits.

The image quality issues were approached on three main fronts. First, the surface processing would use the best of the anti-aliasing strategies previously described -- but do the computations at four times the vertical resolution. With references to Figure 7 this is equivelent to running four sample lines within each scan line. The results of these computations would then be averaged to construct the actual video for the scan line. Secondly, the special requirements of lights were recognized and it was decided to perform more sophisticated processing on them than could be achieved by the sub-scan line techniques. Finally, new data base management methods were devised to maximize the use of available display capacity and yet make management a virtually invisible process to the user.

The DLH day/night visual system has the following characteristics:

- Dual independent channels
- 625 line television standard
- Field update rate
- 1000 polygons and 2000 lights per channel
- 400 polygons and 4000 lights total display capacity

The results have been most gratifying and well received by those who viewed the system prior to its shipment to Frankfurt. Some of the more significant scene qualities observed were:

- Small detail emerges gradually from its background and does not scintillate.
- Long thin features such as runway stripes recede gracefully into their surrounds.
- Scene elements moving perpendicular to raster lines transition smoothly.
- Point lights are well behaved under dynamic conditions.
- Data base management is effective but not observable.

These factors, in combination with careful model design and management, contribute to the impression that a system of this capacity and resolution can be a highly effective simulation device.

We believe that this system will set new standards for day/night CGI image quality. Yet this is not the end of the aliasing story.

Recent Developments

Again, as in the past, each major reduction in aliasing noise has uncovered still another distracting effect. The images produced under static conditions and during most dynamic maneuvers associated with transport aircraft were hard to fault. However, certain pitch and (to a lesser extent) roll motions performed at moderately high rates induced edge effects reminiscent of improper edge smoothing. This was most noticeable on edges which were generally aligned with the raster lines and hence moved through them as the scene shifted vertically. The problem is related to the interlace between successive fields. Interlace is responsible for a well known but not often observed phenomenon in commercial television: vertical scene motion invites an observer's eye to track the interlaced fields and it does so with very little prompting. The result is that the two fields superimpose on the retina producing the impression that the raster is moving slowly in a vertical direction and that it contains only half its proper number of lines.

The observed edge effect appeared to be more severe than might be expected under these conditions. We were fortunate enough to have the flexibility to do some experimenting with the image processing algorithms in the equipment. The effect occurred in spite of field rate update and was worse at frame update rates. The problem disappeared when we switched to a non-interlaced display scan but the implications of this are formidable. Further experimentation with the image processing algorithms demonstrated that substantial improvements could be achieved while operating in the interlaced mode. This too can be added to the list of aliasing solutions and will likely be incorporated in future CGI systems.

FIGURE 1 NOVOVIEW NIGHT SCENE

FIGURE 2 DLH DAYLIGHT SCENE

FIGURE 3

CGI TECHNOLOGY

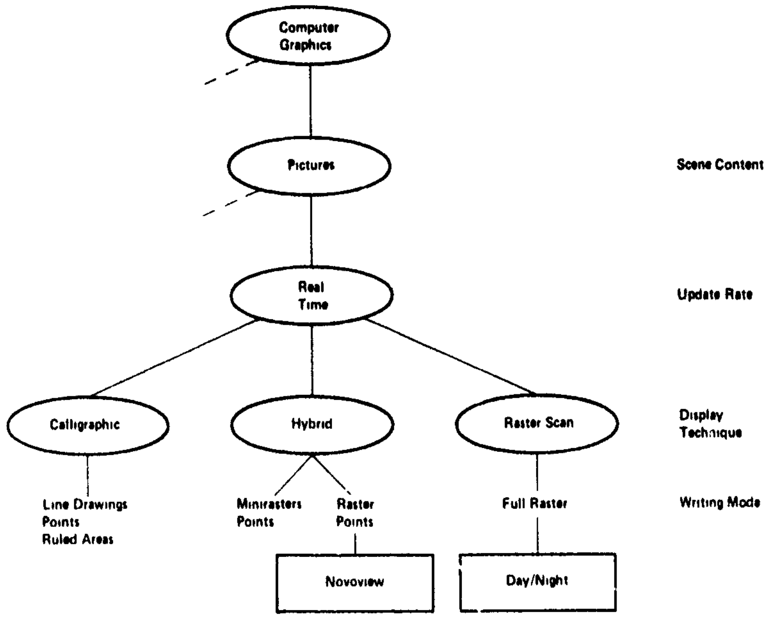


FIGURE 4

RESOLUTION

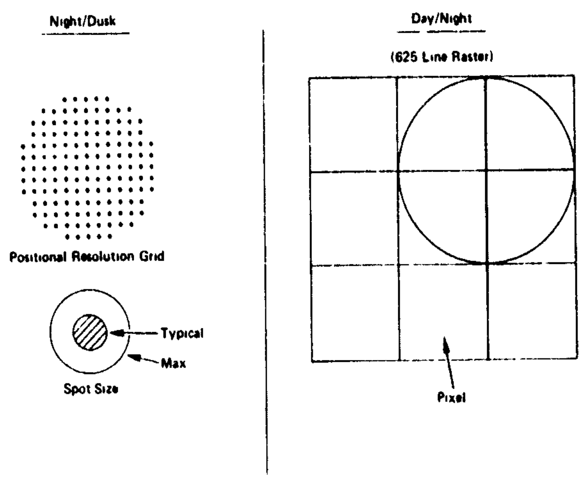


FIGURE 5

EDGE/RASTER EFFECTS

● Edge Smoothing A First Step

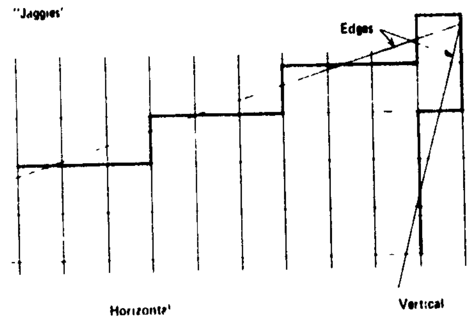


FIGURE 6

VERTEX EFFECTS

● VERTEX QUANTIZATION

Edge Walk Vertical Stepping, Vertex Anomalies

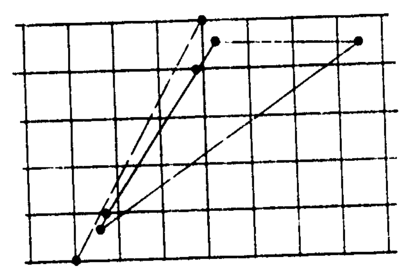
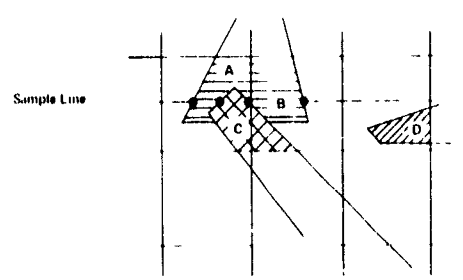


FIGURE 7

SMALL DETAIL EFFECTS

● Scintillation Small Regions, Complex Pixels



Initial Approach Approximate From Sample Line Data

Better Approach Compute At Sub Pixel Resolution

VISUAL CUE REQUIREMENTS IN IMAGING DISPLAYS

Stanley N. Roscoe
Professor of Aviation, Aeronautical
and
Astronautical Engineering and Psychology
University of Illinois

Education

Professor Roscoe received his B.A. in speech and English from Humboldt State University in 1943 and his M.A. and Ph.D. in experimental (engineering) psychology from the University of Illinois in 1947 and 1950.

Experience

From 1943 to 1946 he served as a pilot instructor and transport pilot in the United States Army Air Corps. From 1946 to 1952 he was successively a Research Assistant, Research Associate, and Assistant Professor at the Aviation Psychology Laboratory, University of Illinois, where he conducted research on flight display principles. In 1952 he joined Hughes Aircraft Company where he established a human factors research and engineering program. He was Manager of the Display Systems Department at the time of his return to the University of Illinois in 1969 to establish the Aviation Research Laboratory with a staff of approximately 50, including an annual average of about 25 graduate research assistants.

From 1969 through 1974, as the Associate Director for Research of the University's Institute of Aviation, he developed and directed an interdisciplinary program of analysis, design, and experimentation at ARL. Since 1970, more than 50 advanced degrees in the behavioral, engineering, and computing sciences have been earned by graduate students engaged in research programs for which he was the Principal Investigator. During the 1975-76 academic year, while on leave from the University, he was engaged in research and design studies for NASA's Ames Research Center and the Naval Air Test Center, respectively, as a Senior Scientist in the Display Systems Laboratory of the Hughes Radar Avionics Group. He has more than 100 publications, and his book, Aviation Psychology, is in press for 1977.

Awards and Affiliations

Dr. Roscoe is a fellow and former President of the Human Factors Society (1960-61) and was a Member of the Executive Council continuously between 1959 and 1971. He received the Society's Jerome H. Ely award in 1968 and 1973 for the best papers published in Human Factors in 1966 and in 1972, the Society's Alexander C. Williams, Jr. award in 1973 for his contribution to the design of the Convair F-106/Hughes MA-1 aircraft and weapon control system, and the Society's Paul M. Fitts award in 1974 for his contributions to the education of human factors scientists. In 1969 he was cited by the Radio Technical Commission for Aeronautics for his contributions to the advancement of airborne area navigation as Chairman of RTCA Special Committee SC-116E. In 1975 he was made a Fellow of the Royal Aeronautical Society of Great Britain, and in 1976 he received the Franklin V. Taylor career award of the Society of Engineering Psychologists of the American Psychological Association. He is a Technical Advisor to RTCA, NASA, and the US Army, a consultant to the Royal Swedish Air Force, the Allied Pilots Association, and the Canyon Research Group, and President of ILLIANA Aviation Sciences Limited, a research and consulting group including present and former staff of the University of Illinois and similarly qualified scientists.

VISUAL CUE REQUIREMENTS IN IMAGING DISPLAYS

Stanley N. Roscoe
University of Illinois at Urbana-Champaign

PROBLEM

Frequently during the technological explosion that has occurred since the last World War a highly sophisticated technology has suddenly emerged in the absence of a well defined statement of requirements or methods for effective use. The ability to create and present dynamic, closed-loop images representative of a contact view from the cockpit of a simulated airplane is a typical example and one attended by the usual problems of what to do to capitalize on the evident potential applications of the new capability.

The "Detail" in a Visual Scene

One immediate problem in the application of dynamic visual systems to synthetic flight training in simulators is to select specific values from the wide ranges of available variations in the visible characteristics of dynamic images that determine what is commonly referred to as level of "detail" or "complexity" of the visual scenes presented. The problem is complicated by the fact that "detail" means different things to different people: to the terrain-board model maker, to the computer programer, to the visual system engineer, to the research psychologist, the training specialist, the flight instructor, and the flight student.

Furthermore, to the operational types (the last three of those just mentioned) "detail" will be judged differently depending upon the training application, specifically, upon the flight tasks to be learned in a simulator and subsequently transferred to an airplane. Despite these complicating considerations, if asked to compare or rank the relative levels of detail contained in two or more representative examples of dynamic visual scenes under comparably structured training situations, qualified observers can be expected to arrive at remarkably close judgments, even in the absence of an explicit definition of "detail" or an identification of the physical and informational variables involved.

A Taxonomy of Variables

Thus, while the concept of level of detail clearly exists and is commonly referred to without discomfort by knowledgeable members of the simulation and pilot training communities, the specification of the physical and informational characteristics of a simulated scene and the prediction of the resulting subjective judgments of level of detail present are not completely within our present technological grasp. Clearly, the establishment of lawful relationships among these display variables and their resulting effects is needed.

The physical and informational variables that must be dealt with in defining the visual characteristics of a dynamic imaging system may be classified in various ways, one of which follows:

Enabling variables, such as:

- The limiting resolving power of each aperture in the image transmission chain, including the human eye.
- The image contrast range or gray-scale rendition limit.
- The color rendition in terms of hue and saturation.

Object variables or "ground truth," such as:

- The kinds of things represented (things in the real world the pilot must learn to respond to).
- The sizes of things in the real world that are represented in the synthetic image world (limited by the resolving power of the optical system including the eye).
- The numbers of the various things of various sizes (complexity).
- The movement of things in the real world that may be represented in the synthetic images, including the attitudes, accelerations, and rates of other aircraft (as in an air combat simulator) or of surface vehicles (as in an air-to-ground attack simulator).
- The selectability of intermittently present things in the real world, such as airport lighting systems, or augmented guidance or flight-path prediction cues not present in the real world but of potential training value in the synthetic visual world, the appearance and disappearance of which may be manually selectable or automatically programed in accordance with some adaptive logic.

Pictorial representation variables, ranging from skeletal outlines or point patterns through untextured surfaces to textured surfaces to colored textured surfaces of photographic image quality.

Ambient visual environment variables, such as:

- Illumination representative of day-dusk-night conditions and variable sun angles.
- Visibility representative of variable densities and distributions of attenuating atmospheric conditions.

All of the variables included in this taxonomy are under the potential control of the visual system designer and manufacturer, and while all influence the eventual subjective judgments of visible detail, such judgments

will also be influenced by a set of variables not under the control of the designer or manufacturer; these variables are associated with the specific instructional application for which the visual system is used by operational training personnel:

Operational task variables, such as:

- The type of mission being taught.
- The phase, segment, or specific maneuver within a particular mission.
- The functional components involved in a specific flight task: perceptual-motor (e.g., maintaining the proper flight path and speed on the approach to a landing), procedural (e.g., selecting weapons and weapon delivery modes), decisional (selecting a course of action in the presence of uncertainty as to the immediate situation or in the absence of a predetermined procedure or doctrine).

These task-related variables, in combination with the previously enumerated visual system design variables, serve to influence the subjective judgments of the level of visible detail in the context of the student's performance in the simulator during training. Related to but not perfectly correlated with these judgments are the judgments that would be made in the context of the expected transfer to the student's performance in the airplane.

A Problem in Multivariate Judgment

From the above, it is clear that the rating of the level of "detail" in a dynamic visual scene is a complex multivariate problem. Despite this fact, the ratings of relative levels of detail by independent qualified observers in a well controlled paired-comparison test could be expected to be in reasonably close agreement, as are the judgments of target background "complexity" by photo interpreters viewing aerial ground maps under carefully structured task contexts.

The fact that the consistency of subjective judgments of level of detail can be determined empirically by pyschophysical experimentation makes possible the establishment of multiple regression prediction equations that relate such judgments to the measured physical and informational variables embodied in representative dynamic visual scenes. The temporary inability to define and measure all of the variables involved weakens but does not completely invalidate such an approach; the consequence will be merely that not all of the subjective response variability will be accounted for by the variables that can be defined, manipulated, and measured.

An Experimental Strategy

The practical application of this approach to the establishment of lawful relationships among physical, informational, and performance variables could be demonstrated by a brief and inexpensive experiment involving subjective judgments of levels of detail embodied in representative visual scenes containing known systematic variations in a small number of readily manipulable design and task variables. By holding other less readily manipulated variables constant, a substantial portion of the response variance could be accounted for, thereby validating the approach and indicating the advisability of refining the prediction equations through further experimental manipulations and measurements.

It is essential to recognize at the outset that the suggested approach does not directly address the ultimate questions of the contribution of visual image detail to the effectiveness of flight training in simulators or the transfer of such training to piloting airplanes. The answers to these questions will eventually require experimentation involving actual training and transfer measurement. The purpose of the initial determination of the dependence of judged levels of detail upon display and task variables is the screening of experimental variables to find out which ones are responsible for substantial portions of the response variance; that is, which ones can be expected to make an important difference to the student pilot.

The validity of this approach to the economic screening of a manageable number of visual image design variables to be included in subsequent training and transfer experiments depends upon the validity of our implicit initial assumption that:

> the visual image variables that contribute substantially to pilots' judgments of levels of detail are ones that also contribute to their ability to discriminate features of the dynamic scene that are meaningful in the visual orientation functions required in controlling and navigating simulators and airplanes.

No assumption is made or implied that increasing levels of the variables that influence such judgments necessarily yield increasing increments of training effectiveness; indeed, the actual functional relationships in question may be U-shaped rather than linear with intermediate levels of detail (or complexity) resulting in the most effective discriminations and training. What is implied is that the manipulable image variables that make large differences in qualified judgments of "detail" are ones that should be studied first in training and transfer experiments of manageable and affordable size.

METHOD

An example of how this approach works may be found in a study by Janis Eisele (Eisele, Williges, and Roscoe, 1976) of the Naval Training Equipment

Center, conducted while she was a graduate student at the Aviation Research Laboratory of the University of Illinois. In the case of Eisele's experiment, subjects were asked to make objective judgments of their positions relative to a nominally correct final approach path, in response to a variety of simulated airport scenes, rather than subjective judgments of the "level of detail" represented, but the purposes and strategies of the two procedures are similar.

In either case, the end products are regression equations that show, by the sizes and statistical reliabilities of the coefficients of the various terms, which variables make big differences in pilot responses. In Eisele's experiment, the variables studies were what I have termed <u>object</u> variables, as opposed to <u>enabling</u> variables or <u>task</u> variables, all of which Eisele attempted to hold constant. <u>Subject</u> variables also were not investigated systematically; her subjects were four relatively homogeneous groups of eight flight instructors each, 32 in all. The object variables that she manipulated in a mixed factorial experimental design were four prominent real-world elements in airport visual scenes and one synthetic element not present in the real world.

Image Variables

The visual scene elements in their various groupings are illustrated in Figures 1-4, and their combinations are itemized in Table 1. The real-world elements, in addition to an ever-present horizon and landing aimpoint, included skeletal representations of: 1. a runway outline, 2. a runway centerline, 3. the desired landing zone, and 4. a ground-plane texture grid. The synthetic element was a series of four T-bars that, when present, defined the nominally correct glideslope and localizer approach path to the runway, a variation of the "highway in the sky" concept conceived in the 1950s by Walter Carel during the Army-Navy Instrumentation Program (ANIP). Subsets of these five elements in all their possible combinations were presented to the four groups of eight subjects each.

Experimental Procedure

Static images of the airport scene were projected onto a spherical-section screen mounted in front of a Singer-Link GAT-2 trainer and viewed from the pilot's seat in the cockpit, as shown in Figure 5. The images represented views from the simulated airplane in 27 different combinations of flight attitude and position relative to the nominally correct approach path in accordance with a central-composite experimental sampling strategy, as shown in Table 2. Each subject responded once or more to each of the eight combinations of display elements included in his particular display group from each of these 27 different points of view.

The task was self-paced in that, following one response, the subject initiated the presentation of the next computer-generated scene. The subject's keyboard response alternatives included all combinations of high,

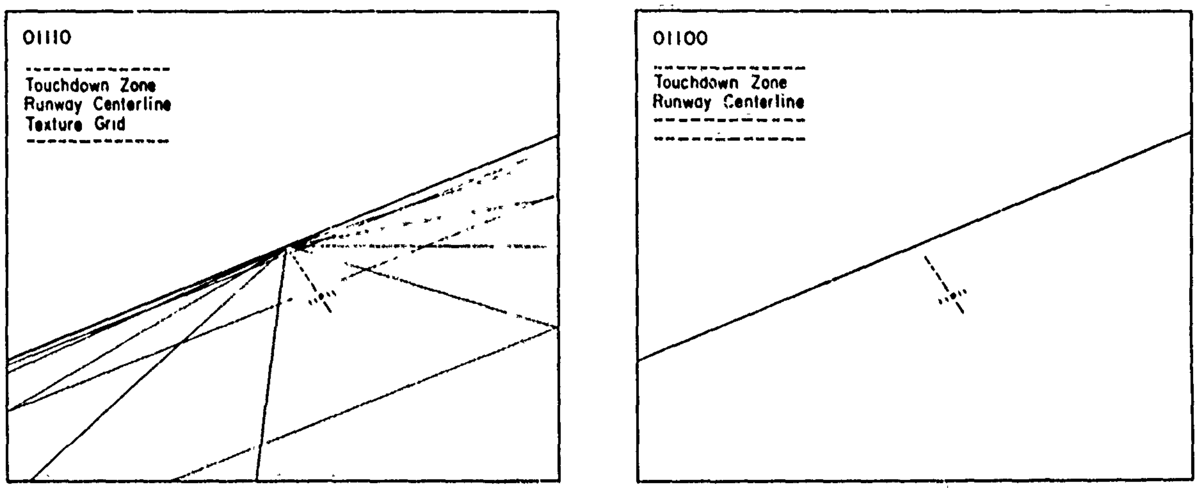


Figure 1. Group I display elements: composite of all Group I elements (left) and composite of Group I elements with Texture Grid omitted (right).

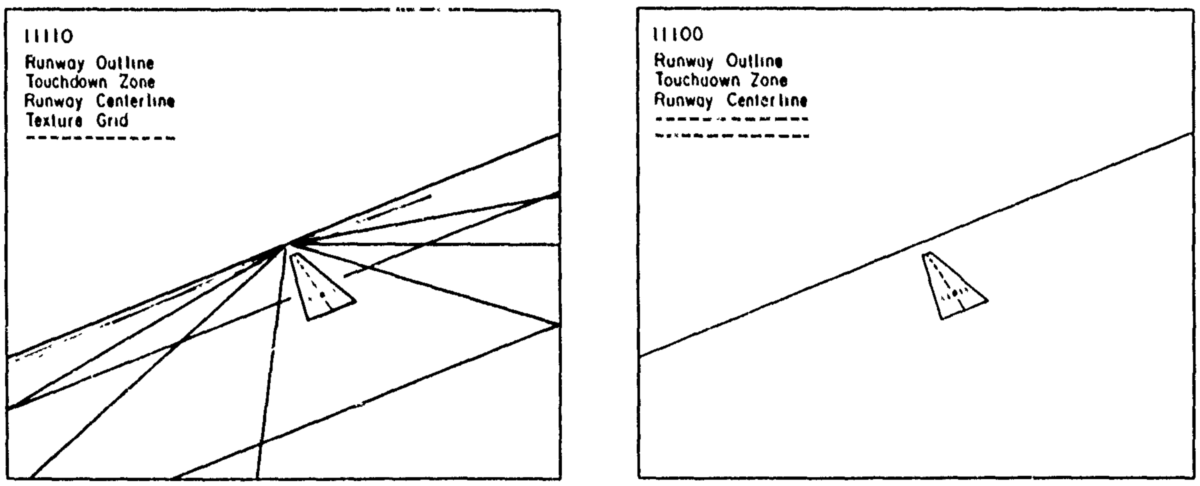


Figure 2. Group II display elements: composite of all Group II elements (left) and composite of Group II elements with Texture Grid omitted (right).

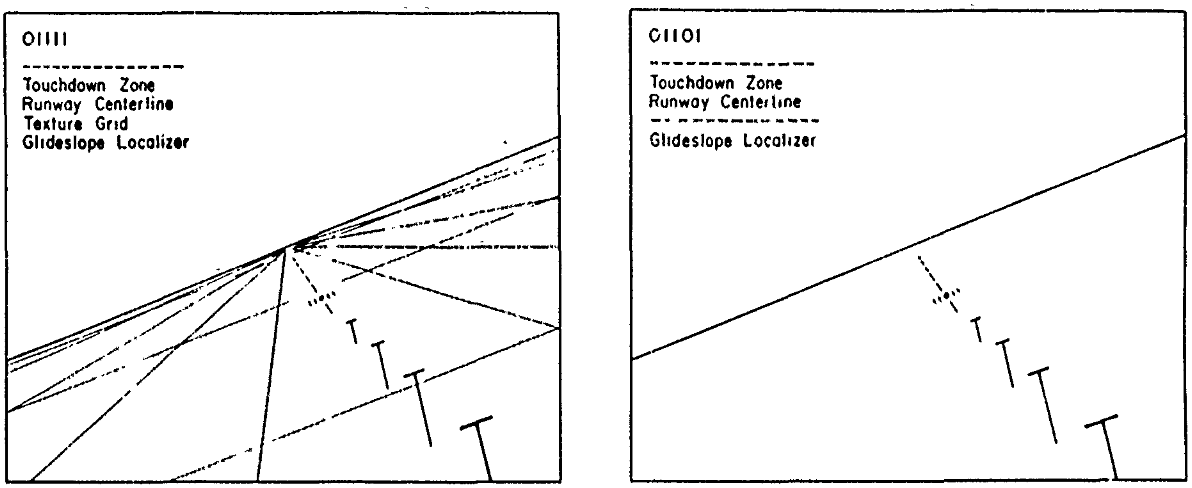


Figure 3. Group III display elements: composite of all Group III elements (left) and composite of Group III elements with Texture Grid omitted (right).

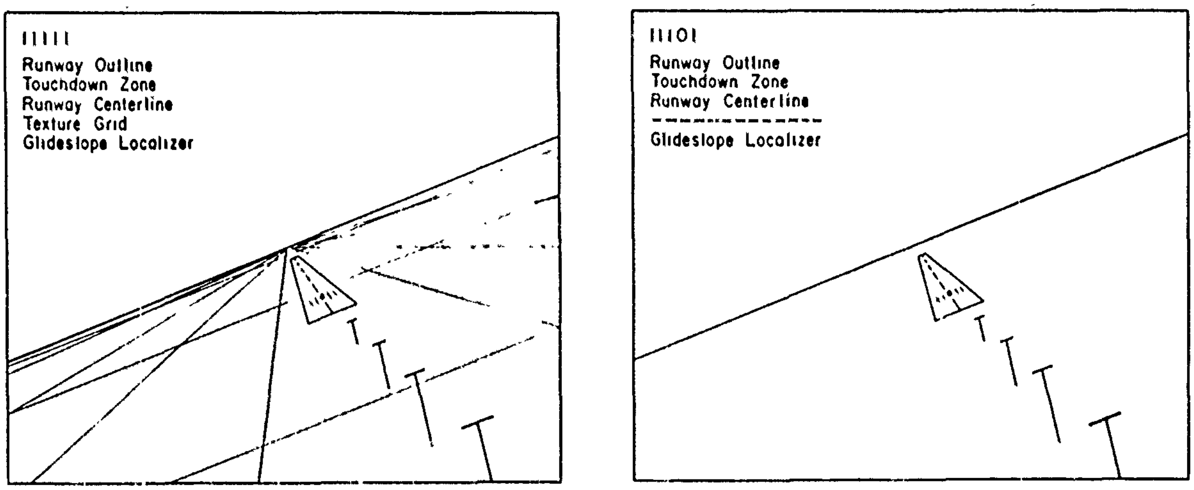


Figure 4. Group IV display elements: composite of all Group IV elements (left) and composite of Group IV elements with Texture Grid omitted (right).

TABLE 1

Visual Elements Present or Absent in Each of the Eight Displays in Each of the Four Display Groups Presented to Independent Groups of Eight Flight Instructors Each

Group I					Group II					Group III					Group IV				
Runway Outline	Touchdown Zone	Runway Centerline	Texture Grid	Glideslope/Localizer	Runway Outline	Touchdown Zone	Runway Centerline	Texture Grid	Glideslope/Localizer	Runway Outline	Touchdown Zone	Runway Centerline	Texture Grid	Glideslope/Localizer	Runway Outline	Touchdown Zone	Runway Centerline	Texture Grid	Glideslope/Localizer
0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1
0	1	0	0	0	1	1	0	0	0	0	1	0	0	1	1	1	0	0	1
0	0	1	0	0	1	0	1	0	0	0	0	1	0	1	1	0	1	0	1
0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	0	0	1	1
0	1	1	0	0	1	1	1	0	0	0	1	1	0	1	1	1	1	0	1
0	1	0	1	0	1	1	0	1	0	0	1	0	1	1	1	1	0	1	1
0	0	1	1	0	1	0	1	1	0	0	0	1	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1

Legend:

0 = without element; 1 = with element

All displays with aimpoint and visible horizon.

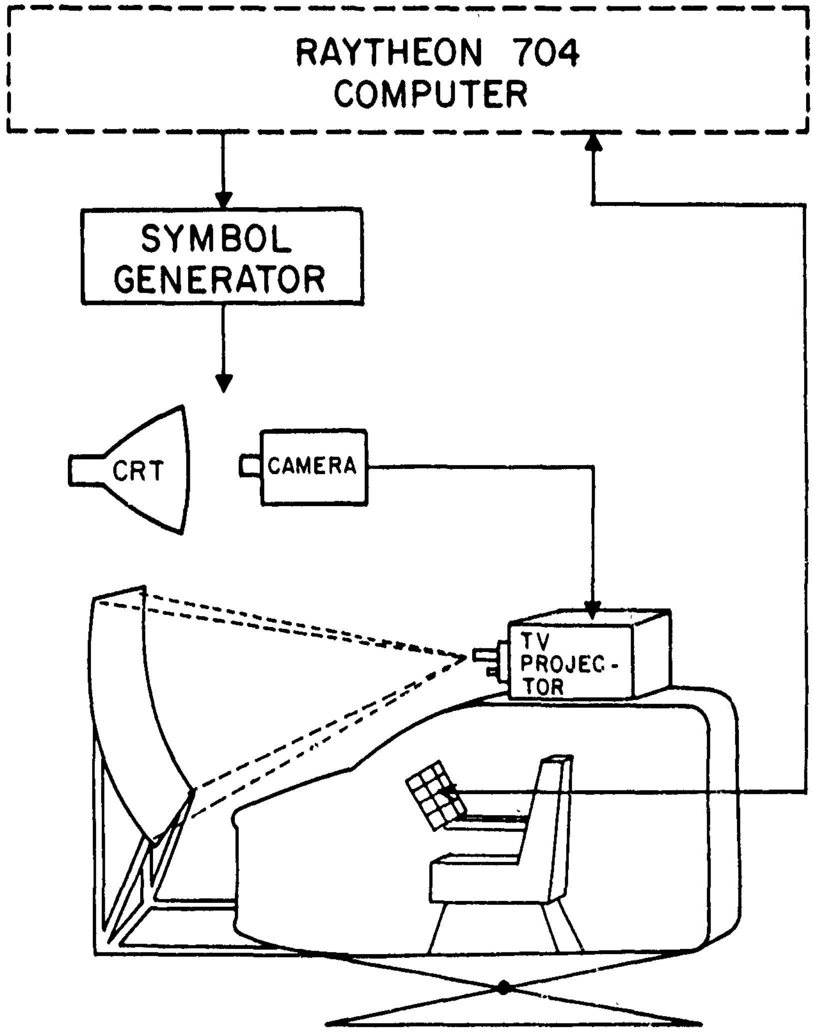


Figure 5. Pictorial landing display simulation equipment.

TABLE 2

Coded and Real-World Values of the Flight Position and Attitude Variables in Accordance with the Central Composite Experimental Design

	Coded Values				
	$-\alpha$	-1	0	+1	$+\alpha$
Position Variables	**Real-World Values**				
RANGE (feet from aimpoint)	1000	2730	4460	6190	7920
VERTICAL DEVIATION (degrees from glideslope)	-1.0	-0.5	0	0.5	1.0
LATERAL DEVIATION (degrees from localizer)	-1.0	-0.5	0	0.5	1.0
Attitude Variables					
PITCH (degrees from horizontal)	0	-2	-4	-6	-8
BANK (degrees from horizontal)	-10	-5	0	5	10

on glidepath, or low, in the vertical dimension, and left, on centerline, or right, in the lateral dimension. The airport scenes were magnified 20% as measured from the subject's task eye position to compensate for the known perceptual bias in distance judgments with imaging displays viewed from short distances. (No such bias was observed in this experiment with the display magnification compensated.)

PARTIAL FINDINGS

Eisele's experiment yielded a giant printout of raw data and tests of statistical reliability. Regression equations were computed for 21 dependent variables, only three of which are presented in Table 3 to illustrate the applicability of the method to her complex, multivariate, real-world problem. Responses to images representing scenes viewed from the five ranges from runway aimpoint called for by the central composite design were grouped into three categories - Far, Medium, and Near - to allow the three resulting equations to show the changing contributions of the five display variables to the discrimination of flight attitude and position as an airplane or simulator "approaches" a "runway."

The three equations presented refer to the accuracy of such judgments; other equations not presented here dealt with the speed, or latency, of responses and a breakdown of correct and incorrect responses and their associated latencies for both lateral and vertical displacements from the nominally correct glidepath. From the three equations presented in Table 3 can be seen the relative contribution of each display variable to the total variance of correct and incorrect responses as a function of range from the Touchdown Zone, or runway aimpoint. It is information of this type that is needed if we are to establish <u>the visual cue requirements for imaging displays</u> to be used in flight training simulators.

The specific implications of Eisele's experiment are that the pictorial representation of synthetic guidance cues, such as a modified "highway in the sky," within a dynamic visual display would enhance a student's landing performance in a simulator. In the absence of augmented guidance cues, the presence of a runway outline contributes most to correct responses at Far and Medium ranges from touchdown, whereas at Near ranges the presence of a runway centerline becomes the dominant basis for correct judgments. Eisele's findings refer only to performance in the training device and do not directly address the ultimate question of transfer of training to another device, such as an airplane.

TABLE 3

Regression Equations and Multiple Correlation Coefficients for Percent Correct Responses as Functions of the Presence (1) or Absence (0) of the Various Display Elements at Far (F), Medium (M), and Near (N) Ranges from the landing aimpoint (underlined coefficients are statistically reliable; $p < .01$).

PREDICTED VALUE		DISPLAY ELEMENT: Runway Outline x_1	Touchdown Zone x_2	Runway Centerline x_3	Texture Grid x_4	Glideslope Localizer x_5	MULTIPLE CORRELATION
Percent Correct Responses:							
y_F	=	$.\underline{185}x_1$	$-.024x_2$	$+.081x_3$	$+.072x_4$	$+.\underline{713}x_5$	$\underline{R} = .745$
y_M	=	$.\underline{117}x_1$	$+.009x_2$	$-.006x_3$	$-.058x_4$	$+.\underline{695}x_5$	$\underline{R} = .707$
y_N	=	$.000x_1$	$+.039x_2$	$+.\underline{165}x_3$	$-.014x_4$	$+.\underline{584}x_5$	$\underline{R} = .567$

ACKNOWLEDGMENT

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REFERENCE

Eisele, J. E., Williges, R. C., and Roscoe, S. N. The isolation of minimum sets of visual image cues sufficient for spatial orientation during aircraft landing approaches. Savoy, Ill.: University of Illinois at Urbana-Champaign, Aviation Research Laboratory, Technical Report ARL-76-16/ONR-76-3, 1976.

EFFECTS OF VARIATION IN COMPUTER GENERATED DISPLAY FEATURES ON THE PERCEPTION OF DISTANCE

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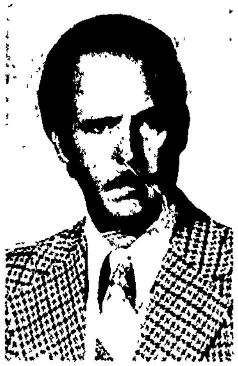

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(Photograph and biographical sketch - see page 225)

EFFECTS OF VARIATION IN COMPUTER GENERATED DISPLAY FEATURES ON THE PERCEPTION OF DISTANCE

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INTRODUCTION

Computer-generated imagery (CGI) is a product of computer and cathode-ray-tube (CRT) integration. Essential characteristics of the physical world are defined by mathematical models and programmed on digital computers interfaced with CRT displays so that dynamic, high fidelity visual representations are produced. The use of this technique of visual scene simulation for training and engineering research has become widely accepted for aircraft and space systems.

The impetus for the research to be summarized in this paper was derived from the part that one of the authors had in the refinement of a computer-generated contact analog display developed for use by the Navy in a digital flight simulator some four or five years ago (Ritchie and Shinn, 1973). For that application the display was comprised of three television-type pictures projected onto seven-feet square screens arranged to provide the simulator pilots a forward field of view 180 degrees wide and 60 degrees high. Two different scenes were generated for use in evaluating the contact analog technique: (1) a runway pattern including a 100-mile radius of surrounding territory and (2) an aircraft carrier moving at 30 knots through open water and trailing a characteristic wake. Surfaces and objects in the scenes were represented in true linear perspective in an effort to maintain realistic three-dimensional views. The display was recalculated and updated 30 times per second in providing a changing scene consistent with the viewer being transported along flight paths "flown" in the simulator.

Three major system limitations acknowledged by the developers of this visual display system were: (1) the 525-line resolution capability, (2) a maximum contrast ratio of 20:1, and (3) a computer capacity which limited to 500 the total number of "edges" which could be used in forming objects and surfaces in the pictures. These limitations were reflected in the following criticisms offered by experienced pilots who were asked to evaluate the system as a flight simulator: (1) There were insufficient cues for making judgments of altitude and velocity. (2) There was insufficient resolution evidenced by the disappearance of small objects when the size of their images, as a function of increased distance, became less than the spacing between raster scan lines. (3) The horizon representation also took on a jagged, stair-step appearance when in crossed raster scan lines at an angle. (4) The horizon appeared to be higher than it should be.

As a result of the foregoing user criticisms, an attempt was made to alleviate the impact of the associated shortcomings while remaining within the physical constraints of system capabilities. The techniques employed in this effort were as follows: (1) The effect of aerial perspective was simulated by generating and displaying a non-uniform gray "fog" or haze-like density function so that colors were desaturated

and objects were less distinct with increasing distance. The effect tended to obscure the horizon making the jagged effect less noticeable. (2) Colors assigned to adjacent areas were selected to maximize color contrast as a compensation for the lack of brightness contrast. (3) The lack of a sufficient number of edges to represent complete detail and numerous small objects was partially compensated for by the use of "nested squares," rectangles, and stripes to increase texture in areas where low altitude manuevering occurred. Colors and desaturation also were combined to add "realistic" texture to the trailing wake in the aircraft carrier representation. (4) To alleviate the inadequate resolution problem, images of small objects which provided critical cues simply were not allowed to become smaller than the raster scan line spacing.

The techniques used in the attempt to overcome system limitations obviously include some distortions of reality. Nevertheless, simple experiments and subjective evaluations by simulator users verified the effectiveness of the modifications in alleviating the noted deficiencies. However, more systematic research is needed to determine the long range effects of such distortions on simulator training effectiveness or, perhaps, on the effectiveness of computer-generated displays incorporated into actual systems operations.

The number of CGI applications is expected to grow with continued improvements in functional hardware and simulation algorithms and with reductions in associated costs. In addition to their recognized advantages over physical models for visual scene simulation in training and research devices, CGI techniques promise significant advantages over traditional visual displays for a number of operational system applications, e.g., as instrument landing (Fig. 1) and targeting aids (Fig. 2) in manned aircraft and for remotely piloted vehicle control and targeting operations (Fig. 3). CGI techniques offer the opportunity, in combination with various navigation systems and pregathered intelligence/ ground truth data, to reduce band-width requirements for real-time sensors since preprogrammed navigation data can be periodically matched with sensor sampled data to enable the CGI generation of the tactical visual scene in real-time.

CGI techniques provide system designers with the opportunity to take advantage of a wide range of human perceptual capabilities in displaying task related information. Potentially, CGI representations can be of very high fidelity incorporating true aerial and geometric perspective, realistic color and minute detail, but not without cost. The cost of CGI can be minimized by including only that level of detail and fidelity essential to user needs. When additional detail only decreases the signal-to-noise ratio, it should not be included. Moreover, when true physical representations consistently produce perceptual illusions which detract from effective user performance, systematic

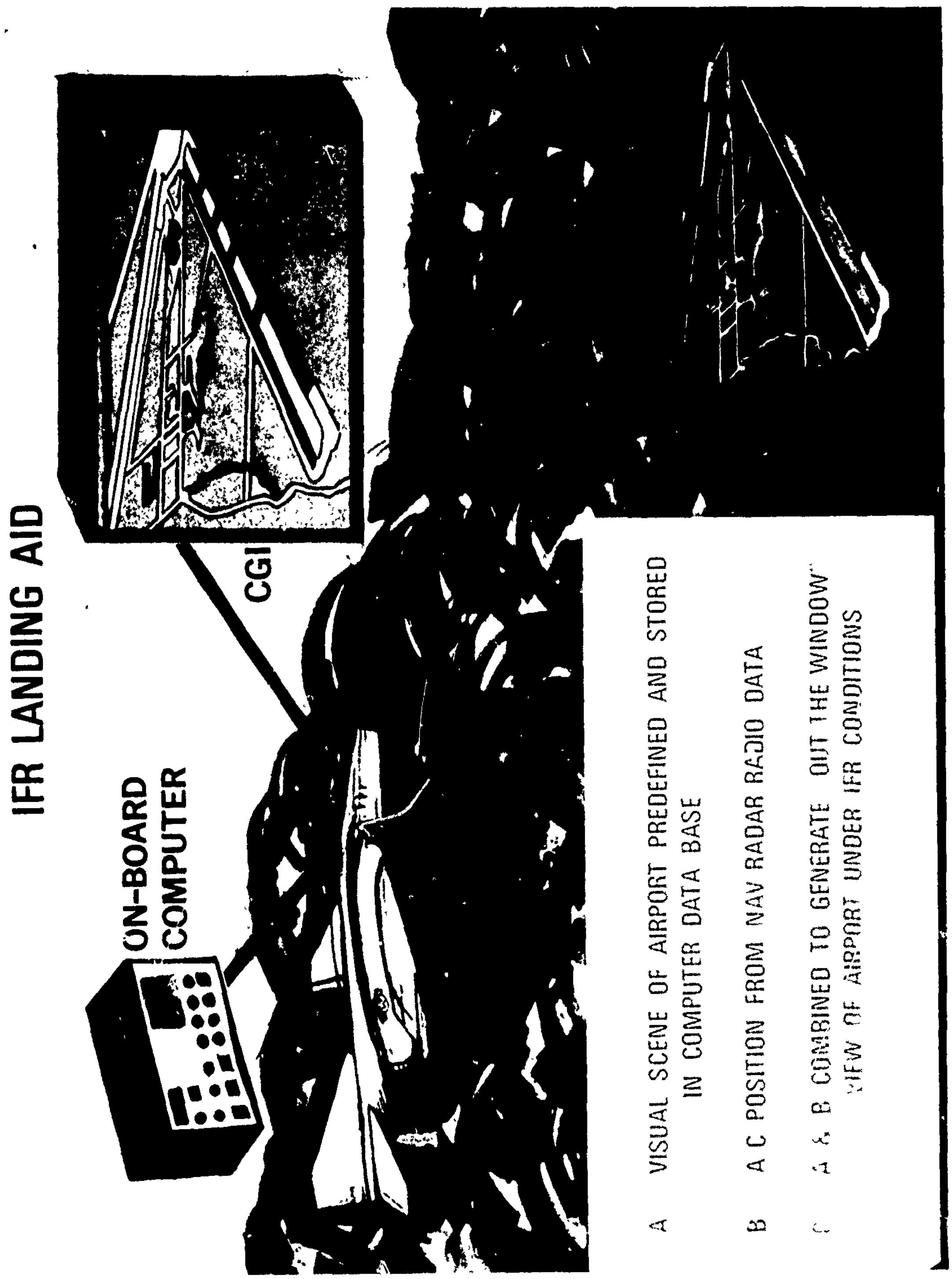

FIGURE 1. ARTIST'S CONCEPTION OF COMPUTER-GENERATED IMAGERY LANDING AID

FIGURE 2. ARTIST'S CONCEPTION OF COMPUTER-GENERATED IMAGERY
ALL-WEATHER TARGETING AID

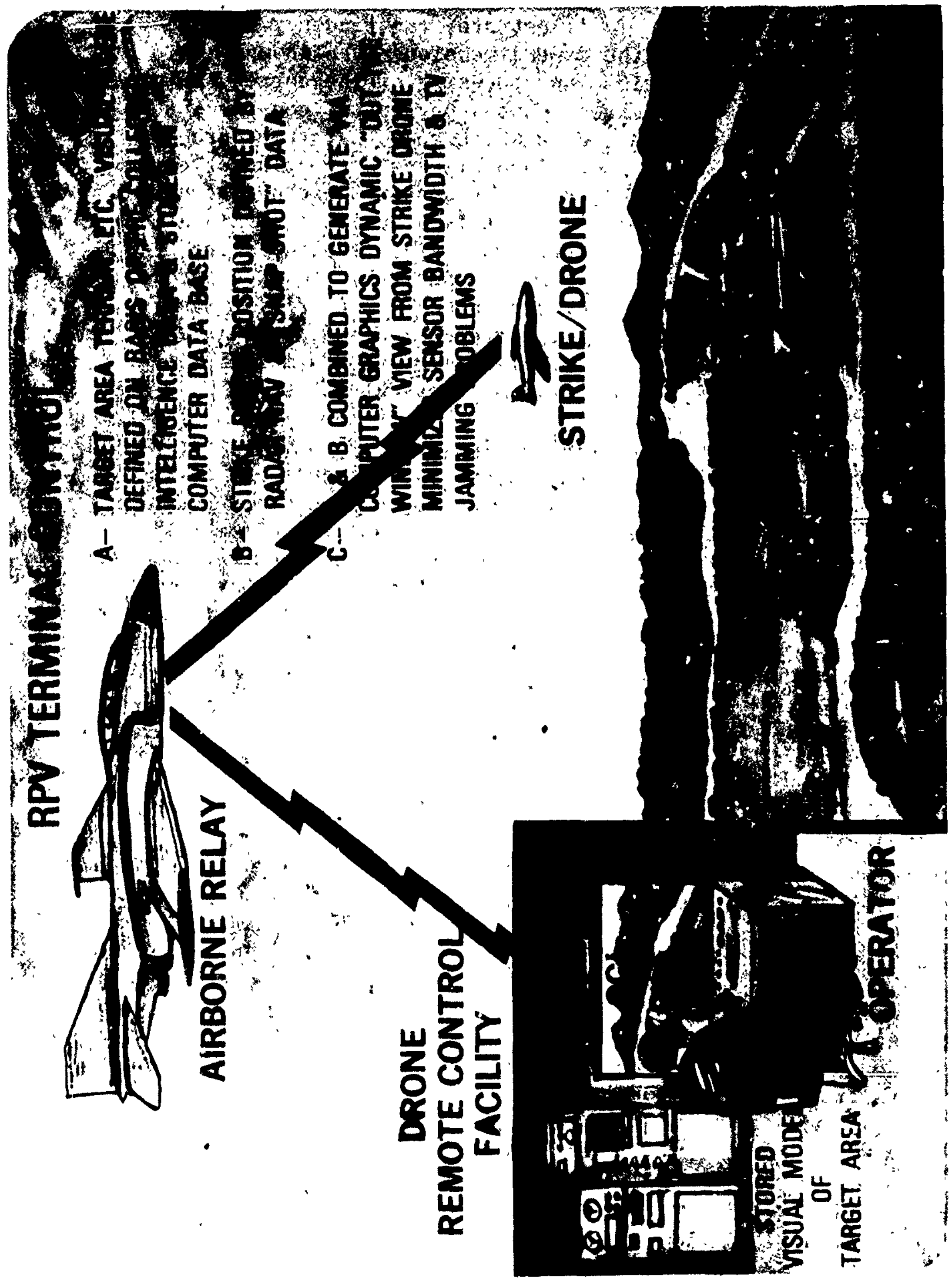

FIGURE 3. ARTIST'S CONCEPTION OF COMPUTER-GENERATED IMAGERY AID TO REMOTELY-PILOTED VEHICLE CONTROL

distortion may be in order. To illustrate, the tendency for an object to be seen as having the same dimensions even though its distance from the viewer varies, and the size of the corresponding retinal image changes is referred to as a perceptual constancy phenomenon. However, there are data which show that there are, indeed significant changes in perceived size as a function of the retinal image variations. And, the relationship between distance and the perceived size of a given object is actually a nonlinear one (Postman and Egan, 1949). Hence, when size is used as the primary cue to distance in CGI, it may be desirable to incorporate computer processed corrections for the known nonlinearity in the relationship. It is this kind of computer-driven CGI principle which will allow the maximum exploitation of man-computer symbiotics to compensate for empirically based human perceptual biases.

Since current human engineering design principles and practices pertain only to the more traditional display techniques and devices, a research program was initiated by the Aerospace Medical Research Laboratory to begin the development of a data base for CGI design principles. The experiments to be summarized in subsequent sections of this paper were a part of that program. More detailed reviews of the program, which included a review of art history, with emphasis on the synthesis of pictorial quality, and a summary of motion picture animation techniques, are available in other sources (Nelson and Ritchie, 1976 and Ritchie, 1976).

CGI EXPERIMENTATION

Method

Stimulus materials for the experiments on computer-generated imagery were derived from the CGI facility developed by the General Electric Co. at Daytona Beach, Florida. The required sequences of stimulus conditions was generated on the CGI system, recorded on video tape and played back for presentation to subjects on the 4.5 x 5.5 ft. display of an Advent Projection System (Model 1000A) at Wright State University. Hence, the method represented a "poor man's" approach to research, but, nevertheless, it provided useful preliminary data on the independent effects of parameters from which complex CGI is synthesized.

The Advent is a color system using red, green and blue phosphor projection tubes with peak wavelengths of 600 nm, 525 nm and 435 nm, respectively. The system operates from an external source with 525 scan lines interlaced 2:1 with the 60 Hz field rate and the 30 Hz frame rate. The Sony Video-Cassette recorder used for recording and playback was a Model V-1800 with 230-line horizontal resolution.

Subjects used in the experiments were seated 14 feet from the display so that the visual angle subtended by the display was $18^{\circ}30' \times 22^{\circ}30'$.

Aerial Perspective Experiment

Subjects. Two groups of subjects, 20 naive university subjects and ten experienced Air Force aircrew members (ACM) were tested.

Stimuli. The stimulus images, generated by the method previously described, depicted uniformly green landscapes underneath a light blue sky. Within each landscape, two dark blue "targets" were depicted as they would appear from an altitude of 1,000 feet. The target dimensions corresponded to structures of 100-feet height, 300-feet width and 10-feet depth. One target served as a "standard" always appearing at the same known distance, 2,000 feet, or about .4 miles, from the subject's vantage point 1,000 feet above the "ground."

The second target provided the "comparison" stimulus, and was presented at one of eight different distances on any given trial. The eight distances depicted were:

Feet	Approximate Miles
3,000	0.6
5,000	0.9
8,000	1.6
12,000	2.2
17,000	3.2
23,000	4.3
30,000	5.6
38,000	7.1

The principal independent variable in this experiment was the aerial perspective-visibility factor. As previously suggested, aerial perspective in CGI involves desaturation of colors, obscuration of detail and increased blurring of the horizon with increasing distance. In the General Electric CGI system to generate the color of an object in aerial perspective "fog," the following formula was used:

$$C_o = FC + (1-F)G$$

where:

C_o = actual color

F = range factor, e^{-kd}
in which k = attenuation coefficient,
and d = slant range to the object (at which distance the object was 50 percent the assigned color and 50 percent fog color)

C = assigned color with no fog

G = fog color

The density of the fog decreases with altitude so that in using the formula one specifies (1) d', which is the distance at which the color of an object is to become desaturated to 50% assigned color and 50% fog color at zero altitude, and (2) h, which is the altitude of the viewer (always 1000 feet in our case). Then the computer calculates the slant range to 50% desaturation of object color.

In this manner four levels of visibility were generated for study. They were identified as 10,000-feet visibility, 18,000-feet visibility, 42,000-feet visibility, and "infinite" visibility (i.e., no aerial perspective factor) .

Procedure. Each comparison target distance was paired with each visibility condition. Having been instructed that the nearest target was always 0.4 miles away and that all targets were the same size, each subject was asked to estimate the distance to the second target to the nearest 1/4 mile. Two judgements were obtained from each subject. Stimulus conditions were presented in random order for 20 seconds each with 10 seconds interval between exposures. The order of stimulus condition presentation was reversed for the second run.

Results. The results are depicted graphically in Figures 4 through 7. Analyses of variance applied to the data obtained from the naive subjects showed the main effects of distance and visibility on perceived distance to be significant ($p < .001$). There also was a significant ($p < .001$) interaction between distance and visibility. There was no significant difference between first and second judgements for naive subjects.

The analysis for experienced aircrew members showed a significant difference between first and second judgements. For first judgements,

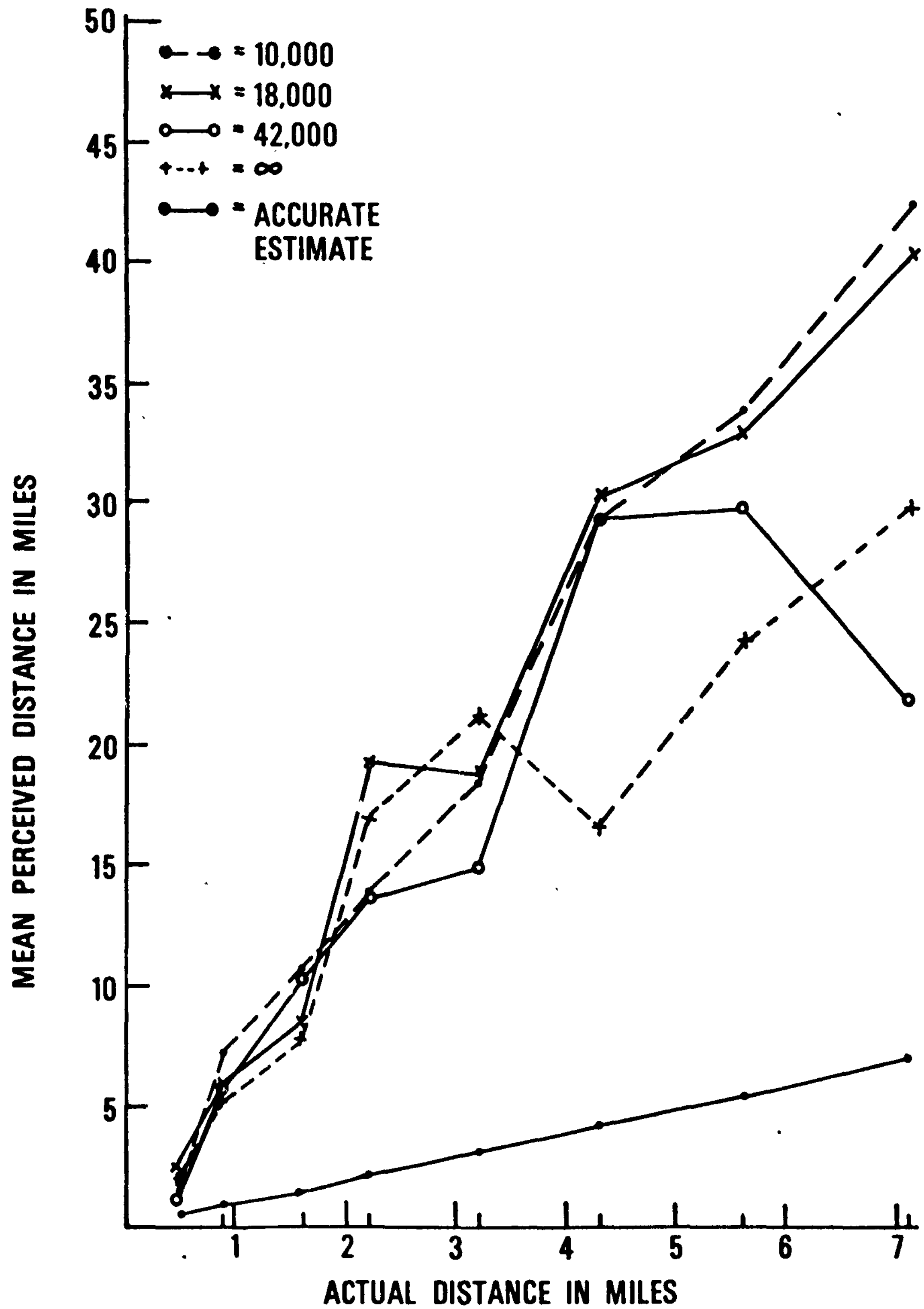

FIGURE 4. DISTANCE ESTIMATES AS A FUNCTION OF VISIBILITY LEVEL (NAIVE SUBJECTS, FIRST TRIAL)

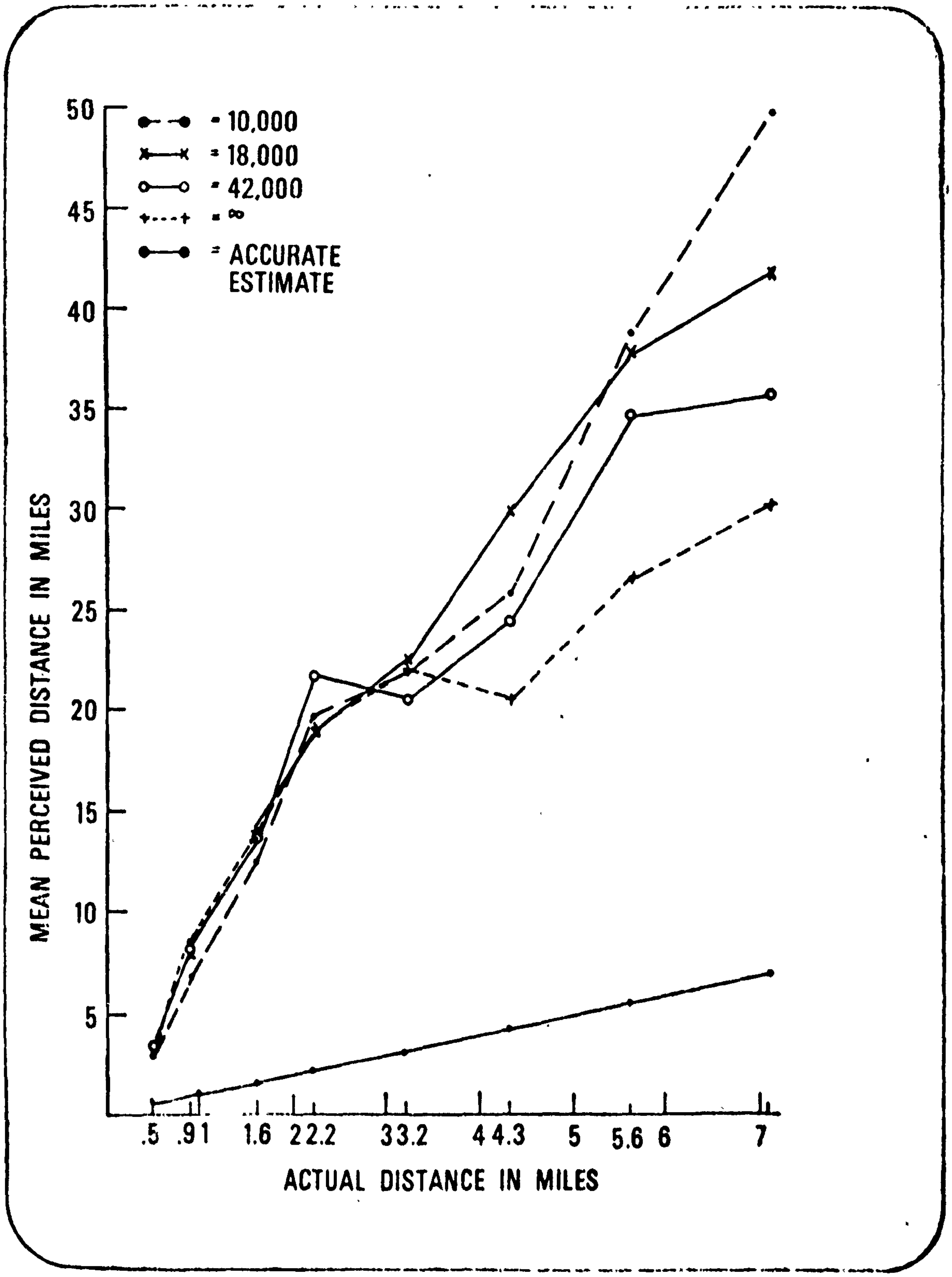

FIGURE 5. DISTANCE ESTIMATES AS A FUNCTION OF VISIBILITY LEVEL (NAIVE SUBJECTS, SECOND TRIAL)

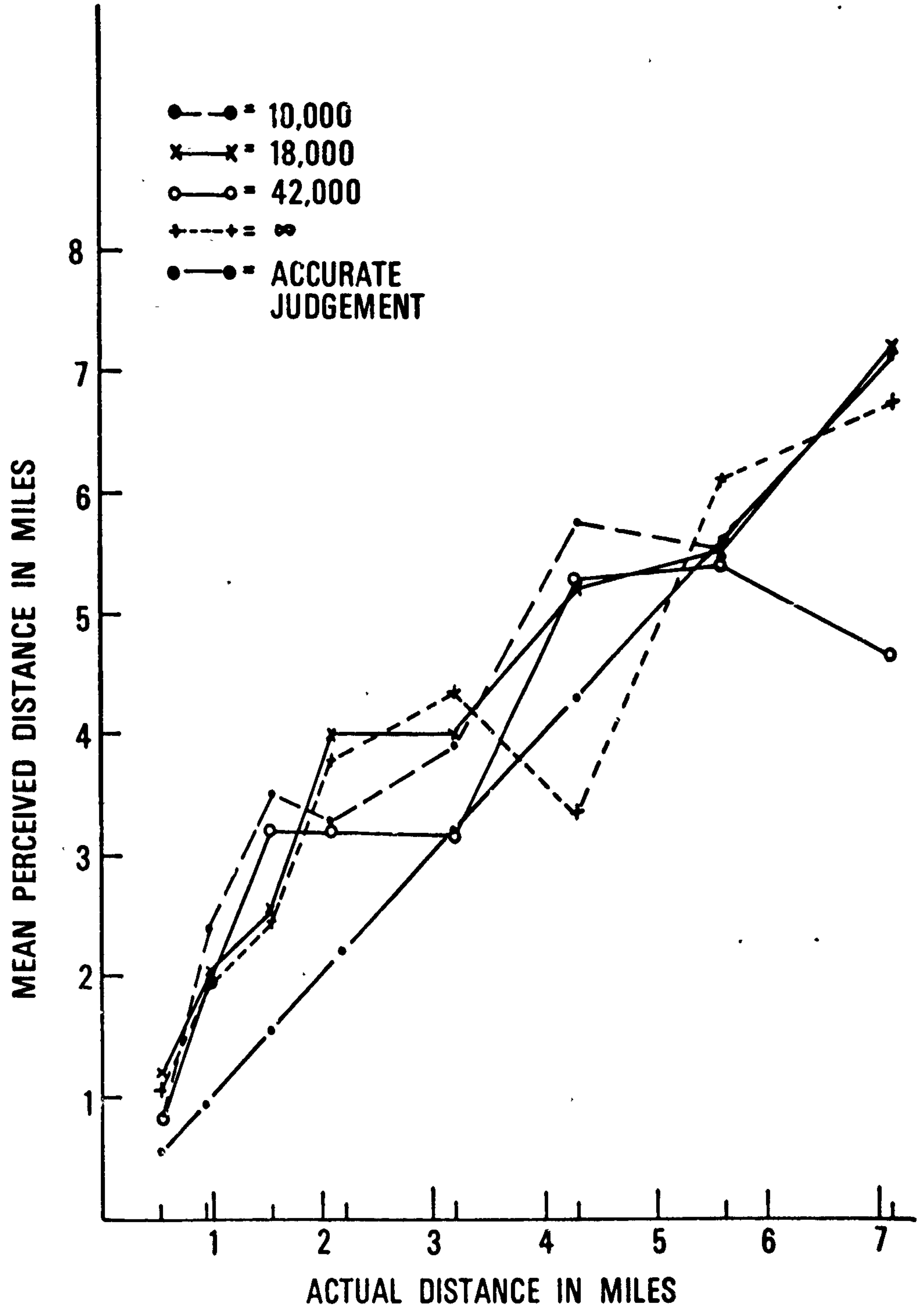

FIGURE 6. DISTANCE ESTIMATES AS A FUNCTION OF VISIBILITY LEVEL (EXPERIENCED AIRCREW MEMBERS, FIRST TRIAL)

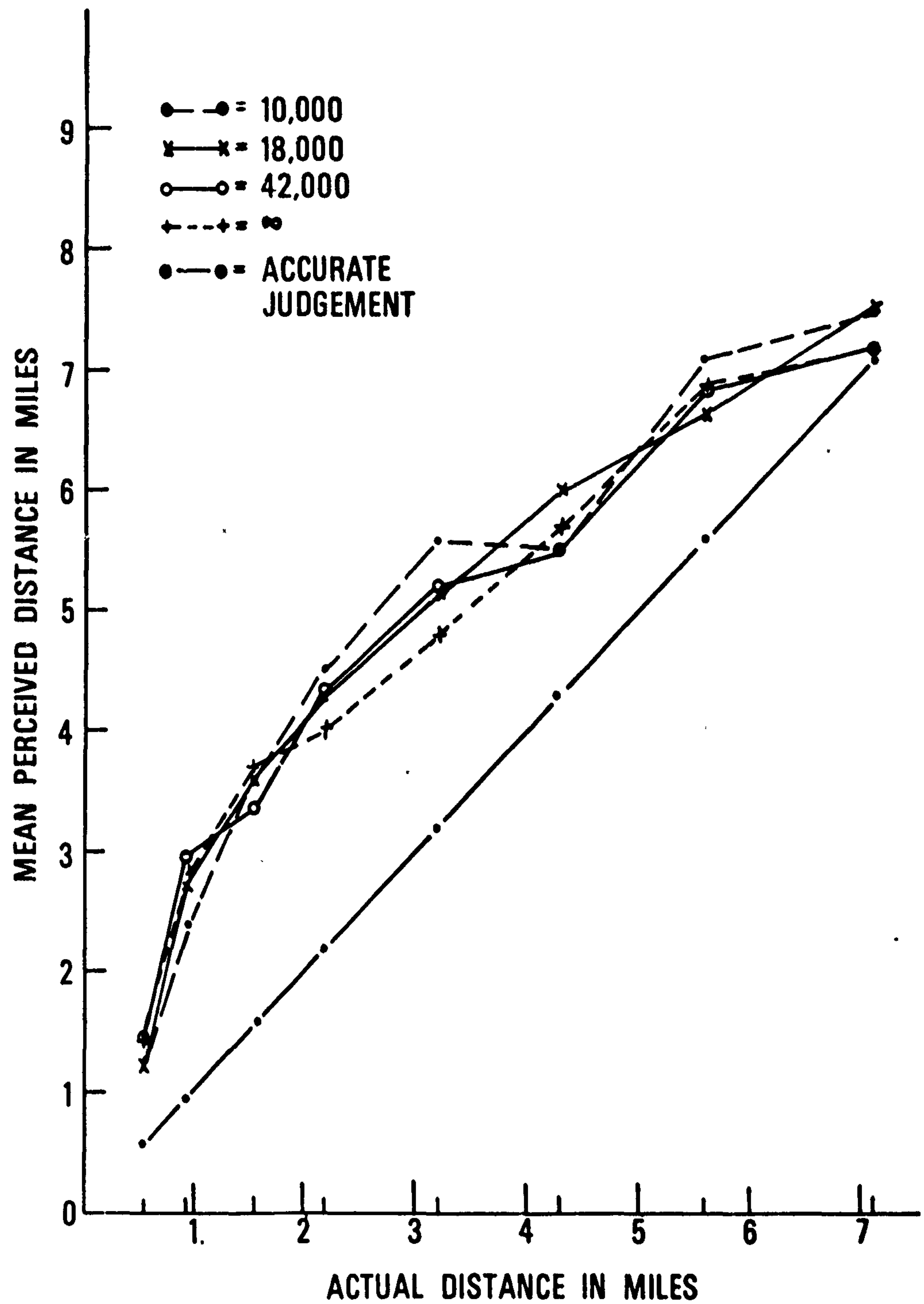

FIGURE 7. DISTANCE ESTIMATES AS A FUNCTION OF VISIBILITY LEVEL (EXPERIENCED AIRCREW MEMBERS, SECOND TRIAL)

the effects of distance, visibility and the interaction between the two proved statistically significant ($p < .01$). However, for second judgement only the main effect of distance was statistically significant.

General Conclusions. The following summary statements reflect the results of this preliminary investigation of simple computer-generated imagery effects on perceived distance.

1. Naive subjects tend to grossly overestimate distances. The error increases with the distance to be estimated.

2. Experienced aircrew members also tend to overestimate distance but are much more accurate than naive subjects. Their error tended to be greater through the middle range of distances investigated and was relatively constant, on the average,(at about two miles) between the slant range distances of 5,000 feet to 30,000 feet.

3. Simulated reduced visibility increased distance overestimation error for both naive and experienced subjects. However, the experienced subjects quickly adjusted their estimates to accommodate for the visibility factor so that the effect was not significant on the second trial.

Texture Experiment

Subjects. Two groups of subjects, 20 naive university students and ten experienced aircrew members were also tested in this experiment. (No subject who was tested in the aerial perspective study was used in this one).

Stimuli. The same targets, distances, and altitude used in the first experiment were used in this one. The aerial perspective-visibility factor was held constant at the 42,000 feet condition. The principal independent variable in this experiment was the landscape background or texture. One level of background texture was the uniform green field used in the first experiment. This was referred to as "0 texture." Three additional levels of texture were produced by overlaying "stripes" of two different shades of green at right angles to each other in a random manner so as to create rectangular blocks. The three levels of texture reflected different widths in the stripes depicted upon the landscape background: 1,000 feet, 2,000 feet and 4,000 feet.

Procedure. The procedure was essentially the same as for the first experiment.

Results. The results are depicted graphically in Figures 8 through 11. The analyses of variance showed the main effects of distance and texture to be statistically significant ($p < .01$) for both naive and experienced subjects. The interaction between distance and texture was statistically significant only for the experienced group.

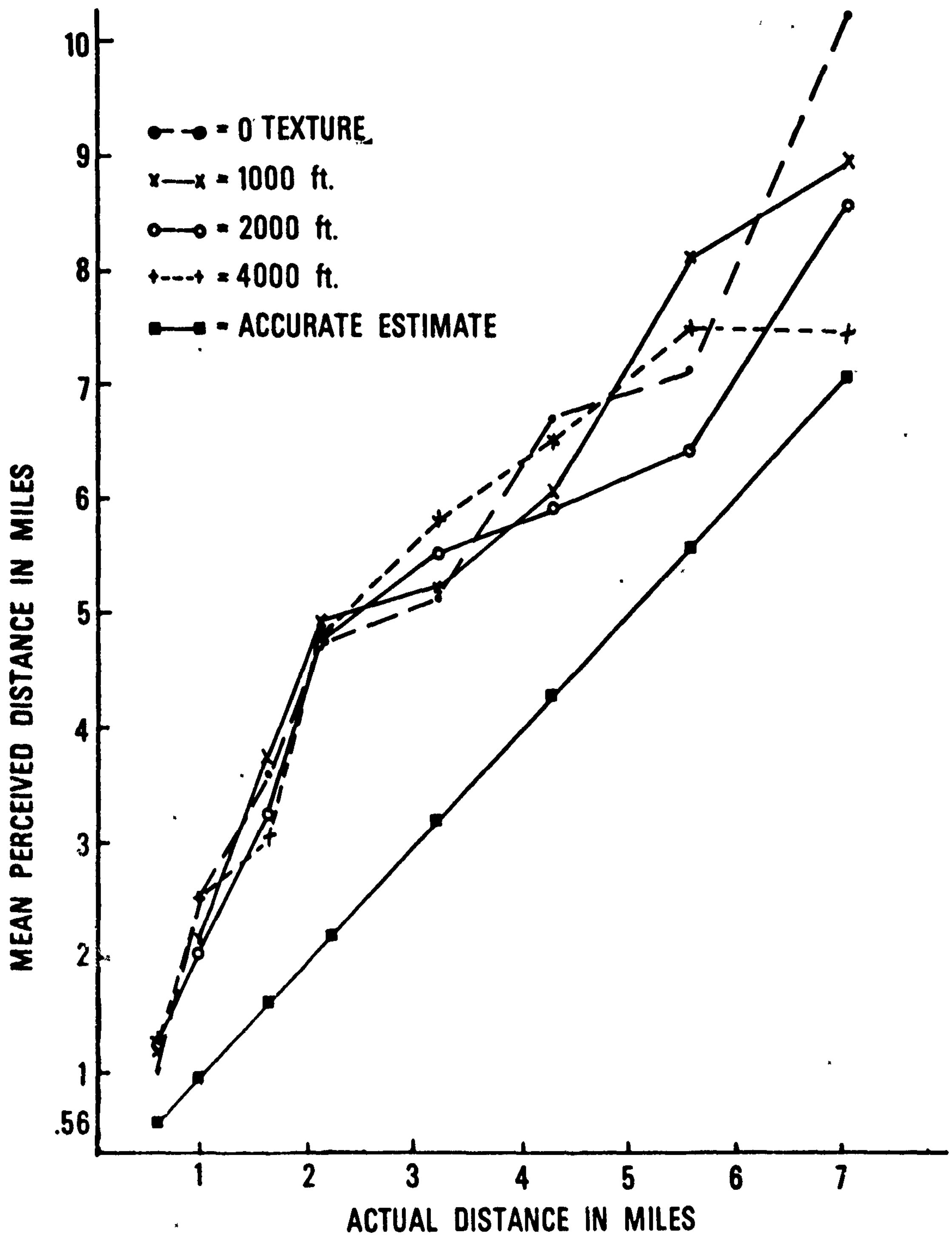

FIGURE 8. DISTANCE ESTIMATES AS A FUNCTION OF TEXTURE (NAIVE SUBJECTS, FIRST TRIAL)

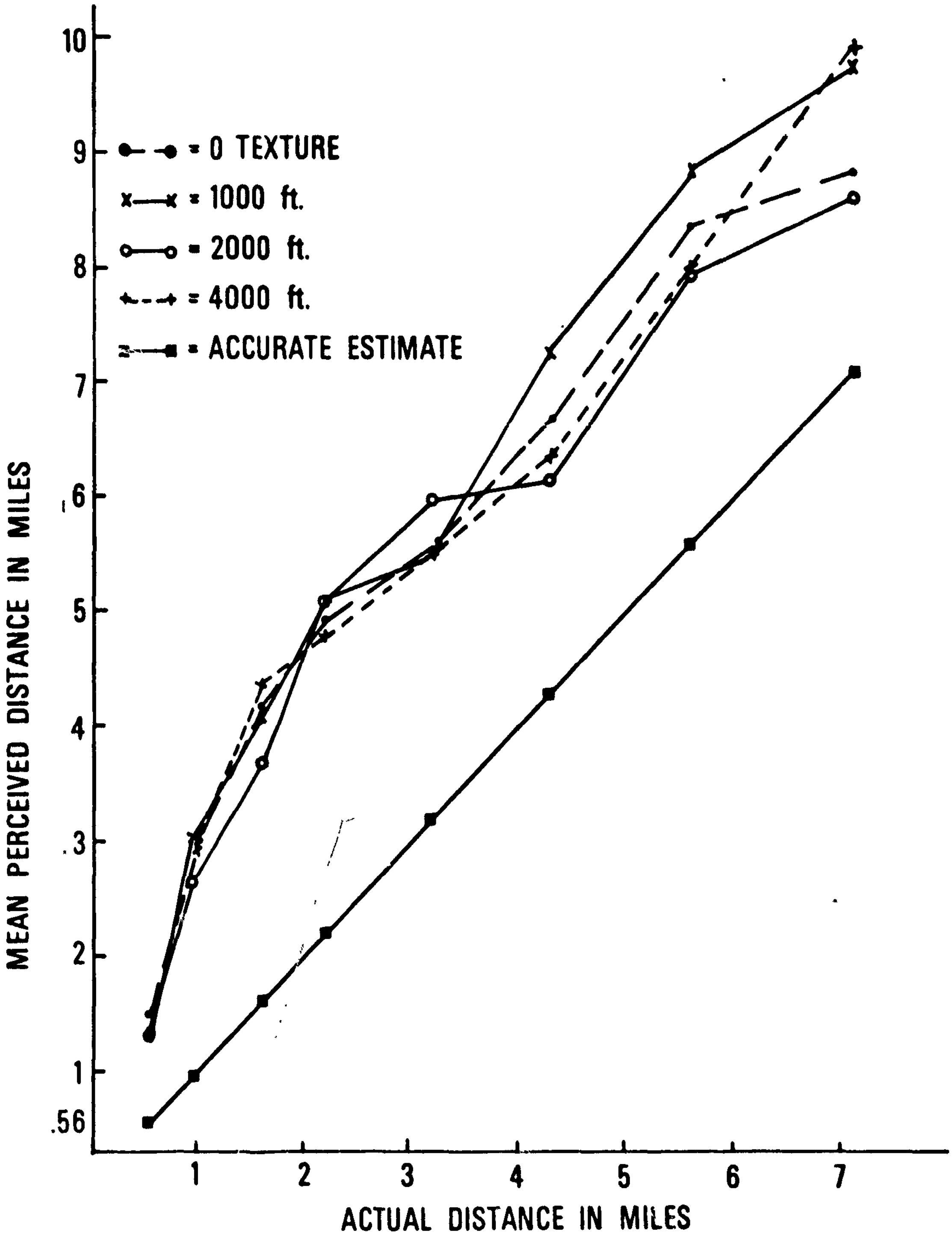

FIGURE 9. DISTANCE ESTIMATES AS A FUNCTION OF TEXTURE (NAIVE SUBJECTS, SECOND TRIAL)

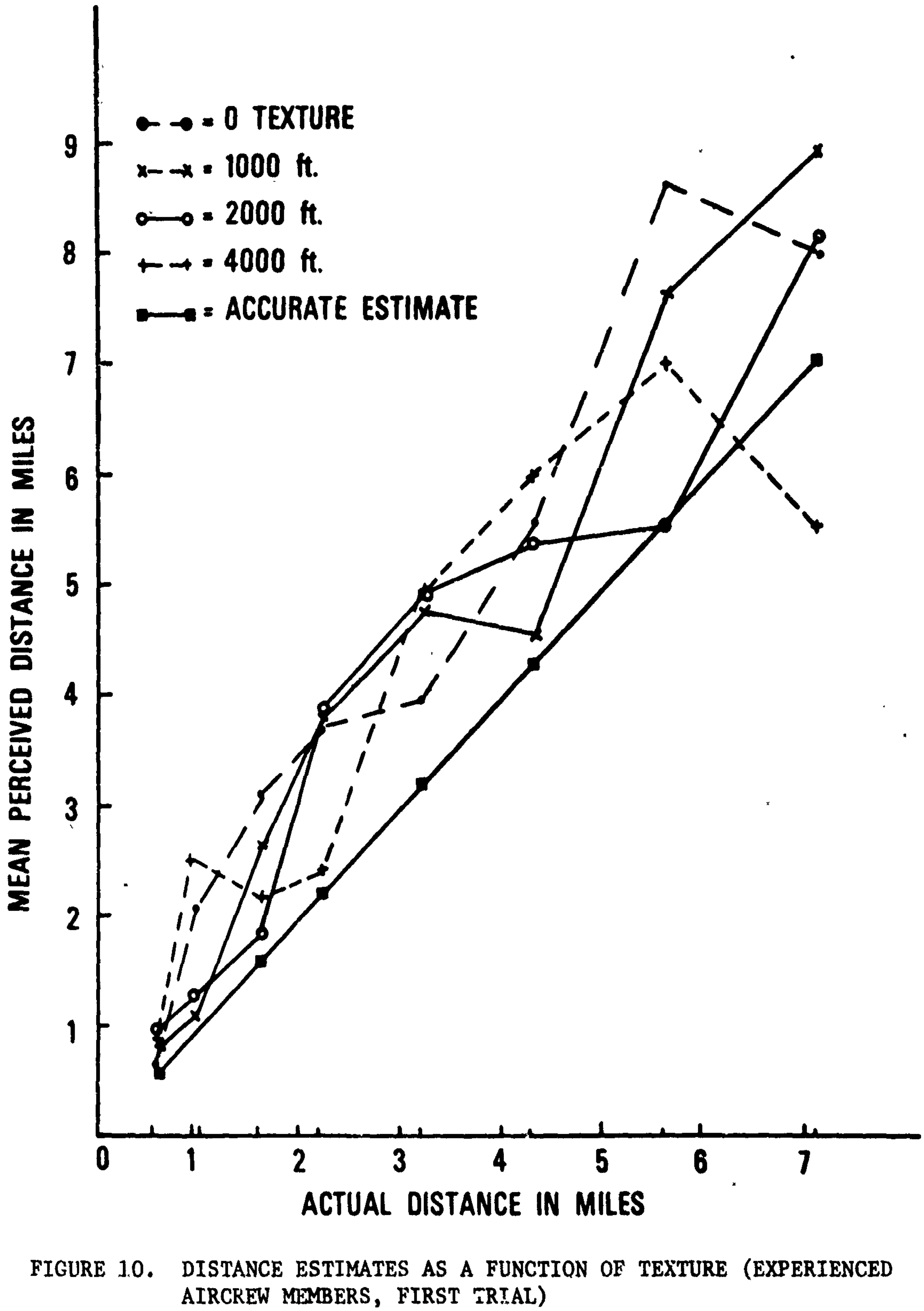

FIGURE 10. DISTANCE ESTIMATES AS A FUNCTION OF TEXTURE (EXPERIENCED AIRCREW MEMBERS, FIRST TRIAL)

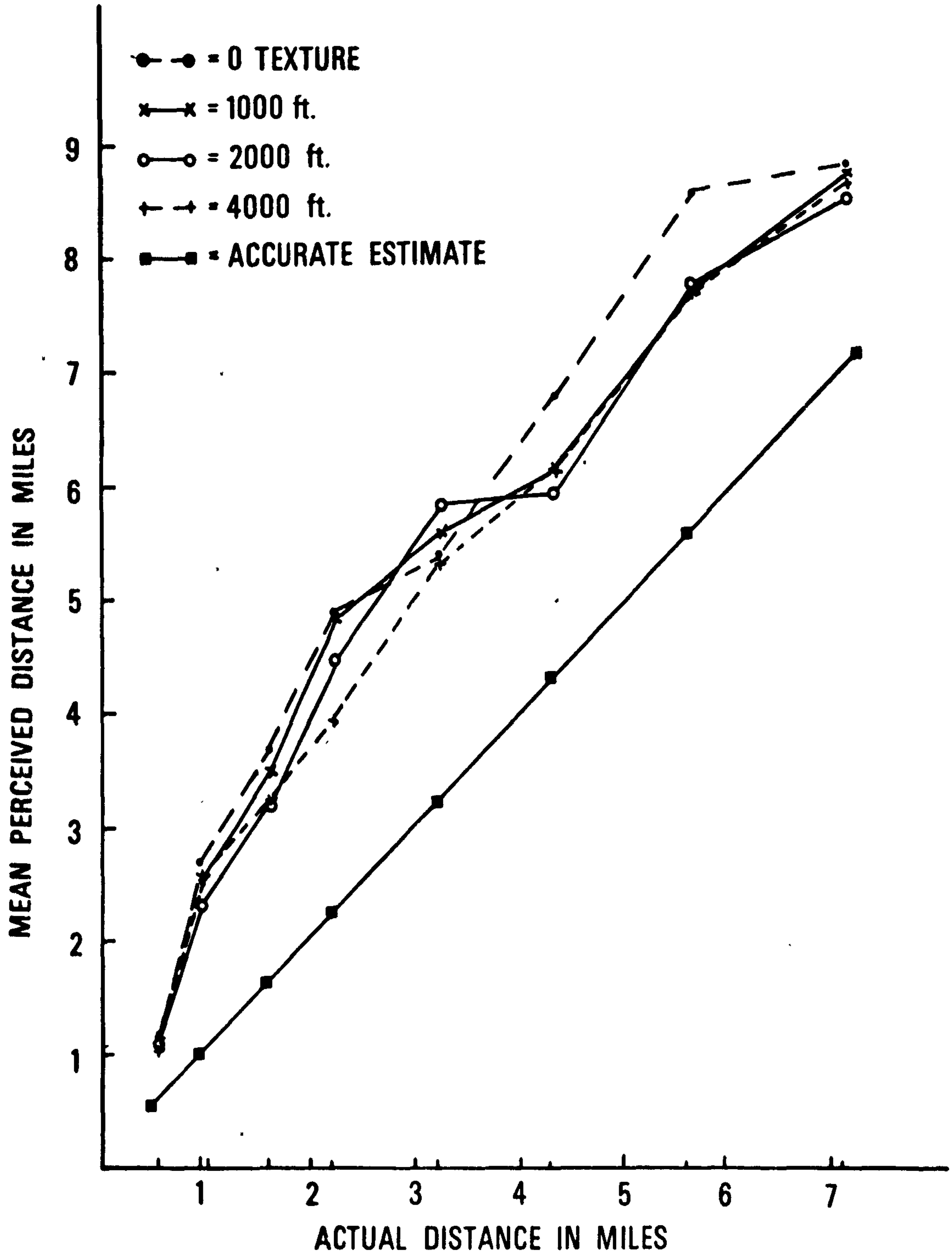

FIGURE 11. DISTANCE ESTIMATES AS A FUNCTION OF TEXTURE (EXPERIENCED AIRCREW MEMBERS, SECOND TRIAL)

General Conclusions. The following statements summarize the results of the experiment on the use of artificial background texturing in CGI displays.

1. Although both groups of subjects tended to overestimate distances, the magnitude of the error on the part of naive subjects was reduced apparently by the texture context of this experiment. (Compare with results of the aerial perspective experiment).

2. The advantage of texturing is less apparent for experienced observers.

3. No particular level of texturing appears to be more advantageous than another. Of course, natural texturing, as produced by forms and fields divided by roads as section lines separated by known distances, would, no doubt, be another matter.

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THE FIDELITY ISSUE IN VISUAL SIMULATION

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THE FIDELITY ISSUE IN VISUAL SIMULATION

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The issue of fidelity remains one of the more popular issues associated with flight simulation. This will most probably always be the case because fidelity is associated with cost. More fidelity: more cost. In fact, the rule is often stated that cost is exponentially associated with fidelity. Fidelity is also associated with training. It is generally agreed that high fidelity gives good training while low fidelity offers poor training, no training, or even training of a negative nature. Because high fidelity is associated with good training, the immediate implication is that the quality of fidelity and training increase at the same rate.

In the past, this line of logic has appeared valid; at least, many of our modern operational simulators have become quite expensive and do provide good training. But today, with the possibility of equipping next generation flight simulators with visual systems that can recreate every detail of the outside world, the cost associated with this level of simulation is such that many would wonder who can afford a good training system if fidelity, cost and training must proceed together; perhaps at some exponential rate!

This is a serious problem. And even though it can be argued that a flight simulator can cost up to ten times that of the aircraft and still be an efficient training tool, the relationships between cost, fidelity and training needs closer scrutiny. The position can be taken, for example, that fidelity, in the popular sense, is not the driving force behind training and cost. To take this position, however, the definition of fidelity must be examined as well as its relationship to training, cost and visual simulation in particular.

The term fidelity, as we all recognize, is a very slippery term. The connotation of the word, when used to describe various systems, is largely a function of the speaker and his background. If, for example, an individual with engineering background uses the term "fidelity," he is usually describing one-to-one relationships between the simulator and that being simulated. In fact, it is not only the engineer with his background in hard sciences that attaches this connotation to fidelity, it is also the user that finds this connotation meaningful. The reason for this is apparent. In the case of the engineer, this definition is comfortable because it is his job to analyze and model physical reality. The user must also define fidelity in this way because most of his experience has been based upon his

perception of physical reality. To use standards other than physical reality offers risks he is not willing to accept. But there are yet other viewpoints concerning fidelity.

Considering the rather awesome fact that visual simulation offers an opportunity to control up to 90% of the information man uses to construct his perception of reality, it seems appropriate to return to one of man's basic disciplines, that of philosophy, for some clues concerning the basic nature of man. This discipline has something to offer because it was the first to suggest that man's concept of reality is not based entirely upon the physical world, but depends to a great extent upon man's interpretation of those physical events which can be isolated, weighed and measured. The discipline of psychology also shares this view. Research has shown time and again the subjective nature of perceived reality and how man fashions his own world based upon the remarkable capabilities of the brain and body to process information received from the five senses. Without belaboring the point further, the important distinction is that this concept of reality has two major dimensions: (1) that dimension which is founded solely on those physical events that are independent of man's interpretation; and (2) that better known dimension which is man's interpretation of raw physical events.

Following the same logic, the concept of fidelity in simulation can be said to have two dimensions: (1) that dimension requiring a close relationship between raw physical events and any synthetic model or simulation of those events; and (2) that dimension requiring a close relationship between man's perception of reality and that synthetic model or simulation which produces an accurate illusion of that reality. The first dimension can be referred to as an objective fidelity where emphasis is on physical events. The second can be referred to as a subjective fidelity where fidelity is person-centered and concerns only man's perception of simulated events. It is this second notion of fidelity that has the most to offer if we are to efficiently manipulate fidelity so as to optimize training and cost. It is also a point of view which frees many of our concepts regarding simulation and allows us to fully exploit the potential of simulation in flying training. Without an operator-centered concept of fidelity, it is tempting to think of a simulator as a simple extension of the aircraft being simulated. Taken within this context, the potential of simulation--by definition--is constrained first by the limits of physical reality itself and second by the extent to which physical reality can be simulated. However, when a subjective or operator-centered concept of fidelity is used, simulation can be seen with all of its unique potential, possessing a flexibility that is limited only by man's ability to exploit complete control over the stuff that makes up a perceived or subjective reality.

In the area of visual simulation, this flexibility goes far beyond the usual advantages of simulation such as problem freeze, reinitiation, record and playback, performance measurement and the like. It involves a full manipulation of the operator's visual world with the opportunity to concentrate on that visual information which is required by the operator to

carry out a specific task at a given level of skill. This is a powerful and key concept for visual simulation in the future. For, to the extent that necessary and sufficient visual information is not made available to an operator at a given skill level, his performance will suffer. To the extent that visual information exceeds that which is necessary and sufficient for a given task and skill level, dollar costs are incurred which are not likely to improve performance or training. By tieing this basic caveat to the fundamental requirement for an operator-centered or subjective fidelity, we are then free to begin the task of defining what is necessary and sufficient for both a training and cost effective simulation; a task that has only begun for flight simulation in general, and for visual simuation in particular.

Using this guideline, it is exciting to explore some of the unique, operator-centered opportunities that visual simulation offers. Three categories of opportunity which come to mind at once are: (1) the opportunity to exploit the native characteristics of the operator; (2) the opportunity to systematically manipulate visual representations of the real world; and (3) the opportunity to create illusions or other forms of artificial reality which have the potential of enhancing training or performance in general. Each of these areas is just now becoming the target of systematic behavioral research.

Consider first the potential of visual simulation to exploit the native or given potential of the operator. Among all of the opportunities that one might think of in this regard, one of the most promising centers about man's capability as a symbol processor and his ability to generate expectancies based on past experience. Give a man a symbol that has acquired some meaning through previous learning and his mind immediately activates an associa^ive chain which transforms that symbol into a meaningful and detailed perception of reality. For example, the word barn, which is itself a symbol, calls up the mental image of a barn which--in the mind of the perceiver--is most likely a red barn with a hip roof situated on a farm with cows, green grass, etc. It may even have a "Chew Mail Pouch" sign displayed prominently on one wall. All of this detail comes from the four letter word "barn." Consider now a line drawing with nothing more than a three-dimensional cube topped with a few lines which represent a hip roof. Go a bit further and imagine a visual computer image generated (CIG) scene which includes the barn and sufficient detail to represent ground and sky. At this point, you have a level of subjective fidelity that will allow an operator to attack the barn or to use it as a navigational fix. It need not be red or surrounded by cows unless that visual information is critical to the task at hand. Let's assume now that the barn should be seen as a church. All that may be required is to add a steeple to the barn and it becomes a church. Similarly, the pilot is a simulated visual environment accepts square wheels on a car or truck as being round. A grouping of boxes can be perceived as a town. And a series of inverted cones can represent a forest. The list can go on and on. The point being that visual simulation can and must take advantage of man as a symbol processor who has himself encoded much of the real world in symbols, waiting only to be activated.

All that is required is a proper visual perspective and that level of visual information which removes sufficient ambiguity to get a job done. The overall subjective experience of the operator and the training potential of the visual scene itself will far exceed the one-to-one relationships between the visual representation of reality and reality itself.

A second area of unique opportunity for visual simulation is the capability it offers to purposefully vary the amount of visual information in a real world representation. Acknowledging the fact that current technology limits the amount of detail that can be brought to bear on a given scene, and that the operator must "fill in" through past experience, it is often desirable in a training situation to further strip away visual information which is not of importance at a particular stage of learning. This technique--easily accomplished with CIG--provides an opportunity to highlight essential visual cues that might otherwise be masked by the detail or visual noise of simulated reality. Future research may show, for example, that learning to land an aircraft can be enhanced through a series of graded visual presentations that systematically highlight the visual cues used by the expert pilot. One could imagine a visual training sequence that first pictures only the basic geometric changes of a runway as distance and altitude vary on a final approach to landing. A second level of detail could include those velocity, altitude and touchdown cues the expert pilot uses for a proper landing. A third level of detail could include all the detail or visual noise that every pilot has to deal with when landing at a real world airfield. This general approach has similar application to many piloting tasks. Consider the problems associated with target detection and recognition or low-level navigation. Here again, the opportunity to manipulate reality in such a way that control is maintained over the internal or subjective mechanisms of the operator is indeed exciting.

A third example of the flexibilities inherent in CIG-type visual simulation systems is perhaps the most fascinating: the opportunity to completely depart from all real-world visual constraints. Within this category of application, our only goal need be the goal of enhancing training or performance regardless of the visual imagery required.

One such application found in the psychological literature is the use of visual cues to provide augmented or artificial feedback. Using this approach, additional information is presented in such a way that it makes a task easier to perform during initial learning. As the student gains skill, the artificial cues are removed. A rather far-fetched application of this concept might involve the addition of a big white "X" on the end of a runway which shows a student the proper touchdown point; or, a target made obvious by a big circle. Almost limitless possibilities exist. Their utility awaits only the proper research.

The opportunity to exaggerate reality is another important capability of visual simulation. Little has been done in this area, but its potential

can be seen when the need arises to capture the attention of an operator, to emphasize some unique characteristics of an object, or to provide visual information that is not normally available due to the resolution limitations of a given visual system. Again, a whole array of opportunities can be imagined from the simplest undergraduate pilot training task to highly sophisticated surface attack and air-to-air training requirements.

Illusion provides yet another example of how visual simulation can be used outside of reality itself. It may be possible, for example, to enhance a pilot's perception of the third dimension--using a two-dimensional display--by manipulating the visual cues which create a sensation of 3-D. How far we can go in this regard, no one knows.

A final example of simulation outside the realm of reality is illustrated by the oportunity to create artificial tasks that are specially designed to train piloting skills. Imagine, if you will, an elaborate series of canyons, spires and walls the pilot must learn to navigate to demonstrate his flying skills. Similarly, tunnels in the sky could be modeled which exercise the student in steep turns, climbs and descents. With careful design of visual environments such as these, the pilot could learn all the boundaries of his aircraft's performance and have a lot of fun in the process. Research will ultimately show the potential of artificial tasks for training.

In summary, an effort has been made to move beyond the popular connotation of fidelity by differentiating two separate dimensions: (1) that objective dimension requiring a one-to-one relationship between raw physical events and the representation of those events; and (2) that subjective dimension which produces an adequate perception of reality as interpreted by the operator. The first or objective form of fidelity can be quite costly and does not guarantee that quality of simulation necessary and sufficient for effective training. The second or subjective form of fidelity is a basic operator requirement which can assure a quality of simulation needed for training, and can be less demanding costwise when an effort is made to provide only that information necessary and sufficient for the training tasks at hand. Several examples have also been given which describe the unique potential of visual simulation to vary and control the subjective world of the operator. Implicit in these examples is the challenge to fully exploit the potential of visual simulation through further research and development both from an engineering and training effectiveness point of view.

If there is a bottom line to this presentation, it is this: Simulation exists only for the operator. And because of this, simulation must be designed for the operator. To remove the operator from the loop or to ignore his demands and contributions, is to hazard great inefficiencies at great dollar cost.

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CLOSING REMARKS
1977 IMAGE CONFERENCE

Professor Robert M. Howe
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When Eric Monroe asked me if I would agree to be the closing speaker at the 1977 IMAGE Conference, I told him that I knew very little about computer-generated imagery. He assured me that I should not worry about that, since he and his people would help me prepare some closing remarks. Well, he indeed did help me, by putting together an excellent program over the past two days. As a result of this, I feel that I have learned a great deal more about CGI, and like the rest of you, I cannot help but be impressed by the tremendous progress made in this field over the past several years, much of which has been reflected in the Conference papers we have heard here.

I suppose one of the reasons I was asked to be the closing speaker is my chairmanship of the newly-formed US Air Force Ad Hoc Committee on Flight Simulation Technology. In addition to being asked to comment on the Air Force R&D program on flight simulation, our committee has been charged with advising whether or not current or future provision for motion should be included in the A-10 and F-16 flight simulators. One might ask what this has to do with visual displays, and in particular, computer-generated imagery. Well, anyone who has ever sat in the cockpit of the ASPT here at Williams and experienced the tremendous motion cues resulting from the wraparound visual system knows how important a wide angle visual system can be in considering motion requirements.

At the present time, it is my understanding that the pacing factor in computer-generated imagery, at least as far as cost and complexity of scene is concerned, is the computer itself, whether it be general purpose or special purpose. It also seems clear that if as much progress is made in computer technology over the next five years as has been made in the past five years, we will see further dramatic decreases in computer costs and increases in computer performance. Thus, I believe that Stan Roscoe's concern over our spending unnecessarily large amounts of money for flight simulators with excessively elaborate visual displays will be answered by dramatic decreases in the cost of CGI within a few years. As this occurs, we are still left with two problem areas which have been highlighted in papers at this conference. The first is the enormous size of the data base needed for CGI involving large land areas. Continued improvements in computer mass-memory technology will help solve this problem. The second problem area is software, in particular, development of compilers that allow automatic generation of computer code for image reconstruction from photographic or other data bases, or simplified source programs that allow easy manual construction of visual scenes. This problem area will require a lot of effort for successful solution, but I believe success will indeed be realized.

In listening to the conference keynote remarks prepared by Senator Goldwater, I was struck by his concern for the tremendous cost of new proposed flight trainers. You will recall that he advised simulator advocates to have completed the necessary R&D proving the need for costly features before asking Congress to provide funding for procurement of such simulators. The truth, of course, is that we do not in fact have at this time the R&D data base necessary for making wise simulator procurement decisions as they affect simulator fidelity. Some of us hope that we are beginning now to invest in the R&D needed to make wise procurement decisions on simulators five years from now. I applaud the concern of Congress over the need for adequate R&D before asking for simulator funds. I hope they remember this when, in turn, they are asked to approve the R&D funds.

Let me turn now to some wild speculation regarding the future direction of computer-generated imagery. I believe we all agree that continued quantum jumps in computer technology, especially in LSI circuits, will inevitably bring us to "photographic quality" computer-generated color displays. This, coupled with easily used software and inexpensive data bases, has the potential of creating a whole new art form. I can imagine artists using a computer-based system to synthesize the equivalent of abstract paintings and other art forms. When he is freed from the time-consuming task of applying paints to the canvas, think how prolific an artist might be in creating new visual effects by calling up and manipulating a vast array of computer-generated color images!

In fact, an obvious extension would be to use CGI to create motion pictures for theatre and home use. This has already been done for cartoon-like animated movies. But with orders of magnitude improvement in information rate capability of computers and displays, the synthesis of photographic quality CGI motion pictures would be a logical development. Now the writer could create visual representations of his characters as he imagines them, with virtually no limitations on the scenarios in which they operate. No longer would the characters be tied to the physical attributes of the real movie actors, as is currently the case. I don't suppose such a development would be greeted with enthusiasm by the actors guild. In a way, this would be a little bit akin to the reluctance of pilots today to substitute simulator time for flight time. One thing is certain, if CGI becomes a major and perhaps dominant factor in the entertainment business, the resulting size of the market would make flight simulation seem small by comparison.

Let me finish by saying how much I've enjoyed meeting many new people and renewing acquaintances with many old friends at this conference. I look forward to seeing all of you at a future IMAGE conference. On behalf of all of us, I'd like to thank our HRL hosts here at Williams Air Force Base, including our chairman, Eric Monroe, for their wonderful hospitality, for arranging the outstanding entertainment last night, and for putting together an excellent conference program.

THE 1977 IMAGE CONFERENCE
17 - 18 MAY 1977

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